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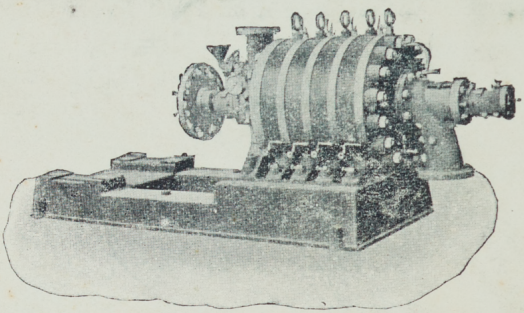

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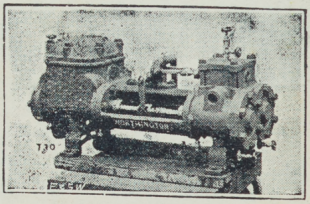

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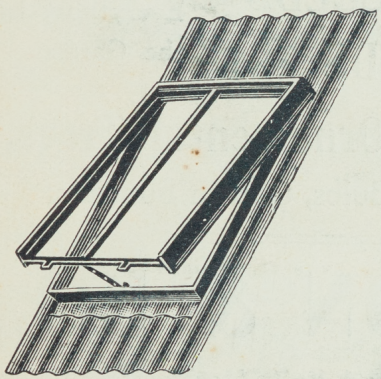

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THE AUSTRALASIAN: "The work under notice, which has special reference to the utilisation of artesian and sub-artesian water, is the most valuable contribution to the literature on the subjects dealt with that has yet appeared in Australia. . . . The greater portion of the work deals with the artesian system of New South Wales and Queensland, and this will prove most interesting reading to all who have devoted any attention to the development of the vast inland regions of our island continent. . . . The prospect he sketches of what may be accomplished by means of artesian water promises a great future for the central region that is underlaid by the water-bearing beds of porous rock. Carefully studied plans of boring and well-making are given, and also methods of raising water from sub-artesian wells. The plans for irrigating lands of different formations are numerous, and readily understood, and a full description is given of all machinery required for getting land into order for irrigation, together with the methods of distributing water. A question that has hitherto attracted very little attention is dealt with by Mr. Cox, and that is the utilisation of the power from bore water. What has been accomplished by irrigation from bore water at the Moree Irrigation Farm, is described, and some excellent photos. of the orchards and cultivated fields are given. The necessity of proper drainage of irrigated land is shown, in order to prevent the accumulation of alkali on the surface, of souring, or water-logging the soil, and to prevent fevers. The chapter on saltbush and its culttivation is both interesting and instructive. Mr. Cox has treated the question of irrigation by means of artesian water from the point of view of an engineer, and his work will be of great utility to all engaged in the practice of irrigation. From the reading of this book one naturally arrives at the conclusion that the artesian area of Australia—the lone 'Never Never' land of a few years back—is destined in the future to become one of the most important regions of the Commonwealth."

SYDNEY MORNING HERALD: "No Australian question has been the subject of so much discussion with so little result as irrigation. Appealing strongly as it does to the imagination, the subject has been rushed by successive generations

of would-be public benefactors. Now after a long series of Royal Commissions, conferences, and investigations and clamour generally, there appears some prospect of our river waters being utilised, and our artesian waters tested in a practical manner. Mr. W. Gibbons Cox comes forward with an opportune work on irrigation from river and artesian supplies. Mr. Cox writes with engineering experience in Great Britain and America, to which he has added a long working association with Australian conditions, and particularly with artesian waters. . . . The chief value of the book will be, perhaps, for the individual irrigationist. The author goes into detail on most phases of small schemes. For instance, he describes, from personal experience, what he considers the best machinery for bore-sinking, and deals in the same way with the driving of tunnels, rock-drilling, windmills and their erection, and oil engines. Then he goes into soils and their suitability to receive water, and devotes a considerable portion of the book to the most approved methods of application. He takes various crops and fruit trees separately, and gives a lot of sound information on the question. The sinking of wells, the erection of reservoirs, ditches, checks, and grading are all considered."

Sydney Daily Telegraph: "A valuable addition to Australian agricultural literature is made by Messrs. Angus and Robertson, who have just issued a work on 'Irrigation and Land Drainage,' from the pen of Mr. W. Gibbons Cox, C.E., a contributor to these columns of several articles on the same subjects. It goes without saying that these questions are of paramount importance to New South Wales—also to the other States of the Commonwealth as a matter of course—and Mr. Cox appears to have dealt with them in an eminently practical manner. He has had a wide experience in four of the States, as well as in the western States of America and in England, so that he should be qualified to speak authoritatively. The major portion of the book is concerned with irrigation, both by surface and subterranean waters, and each subject is carefully elaborated with the aid of numerous illustrations. Land drainage, the corollary of irrigation, is dealt with particularly in the light of the development and utilisation of artesian and sub-artesian supplies. A coloured map, at the end of the book, shows at a glance the artesian and sub-artesian areas for the whole of the continent. The book will, no doubt, materially assist the inland farmer in settling many vexed problems."

Sydney Mail: "Since irrigation in New South Wales has been on the tapis for such a length of time without

any of the schemes having resulted in practical illustration, one should welcome any additional light on the subject. . . . Mr. Cox, whose writings in the SYDNEY MAIL are, no doubt, familiar to its readers, discusses extensively the artesian water supply of Australia, and he avoids as much as possible technicalities in his descriptive matter. This makes the reading of his work both interesting and pleasurable, to say nothing of the educational value of it. He explains variation in flow, which question has puzzled many a station owner, both in Queensland and New South Wales. A good deal of his remarks on irrigation has already appeared, but in a curtailed form, and the reader will now be able to enlighten himself on hitherto unexplained points. His chapter on evaporation is well worth reading by all stock men, whether they have artesian bores or not. The small settler will find in the book a good deal of information on the arrangement of the land intended to be irrigated, on ditch making, and the amount of water to be applied. A chapter is devoted exclusively to saltbush and its cultivation. Then, further, matters of general interest are to be found in the chapters on drainage of lands and farms. . . . I can thoroughly recommend Mr. Cox's book."

MELBOURNE AGE: "No more important subjects than those indicated in the title of this book affect the well being of Australian pastoralists and agriculturists, and any reliable contribution to the somewhat scanty literature on them is sure of a hearty welcome, more particularly when it comes from the pen of such an experienced hydraulic engineer as Mr. W. Gibbons Cox. He has gone thoroughly into his subject from the strictly utilitarian viewpoint, and his carefully gleaned facts and figures, as well as his manifold instructions as to the correct way to irrigate and drain, should be of substantial assistance to the farmer. His conclusions regarding artesian water supply suggest the possibility of a future agricultural population on the western plains of Queensland and New South Wales, which are now entirely devoted to sheep and cattle raising. He considers that there are immense accumulations of water in the artesian areas, which will be amply replenished in the future as in the past; that the intake area is far greater than was originally supposed, and that an additional supply is provided by the rivers and creeks which cross the outcrops; that the supply is a comparatively constant one, and may be considered adequate for a very much increased production on the surface, and for utilisation for irrigating; that under intelligent systematic treatment artesian water

may be safely relied on for raising crops of all kinds, and that the reported failures in its application are traceable to the use of too much water and the lack of proper cultivation and drainage; and finally that as the outflow is increased the water will become of a better, if not perfect, quality. These three last conclusions are obviously of the most important character, and Mr. Cox's long years of study and practical experience entitle them to respect. Another valuable aspect of Mr. Cox's book is contained in the practical teaching he affords as to the best application of irrigation, and this teaching is materially assisted by a series of plans and diagrams, together with hints as to the construction of wells, dams, channels, and pumping plants. Altogether the volume covers the subject in a markedly adequate fashion."

The Australian Field: "This work comes as a welcome addition to the literature which deals with Australia's greatest problem—the conservation and distribution of water. Rain does not always come when it is wanted, and sometimes it comes like a deluge. It is the manifest duty of those who choose to make Australia their home to study the best ways and means of minimising the disastrous effects of this irregularity, and they will find valuable help in the book before us, which contains between its two covers an immense amount of information on artesian and sub-artesian water supplies, irrigation and drainage, compiled by one who not only thoroughly knows Australia but is evidently a most earnest student of the subjects with which he deals. To people in other lands and to too great a number here, who regard Australia as a land hopelessly subject to droughts, it will come as a revelation that there is such a large area from which water spouts up in no small force and volume from great depths as soon as bores are made into the water-bearing strata. There is in New South Wales an intake area of approximately 18,000 square miles on which the mean annual rainfall is 25 inches, and another 50,000 square miles in Queensland. It is estimated that 3,971 million cubic feet of water fall annually on this area. Mr. Cox, differing from some other authorities, thinks it fair to assume that 30 per cent. of this rainfall is absorbed by the intake beds, which would mean that 7,445,625,000 gallons per diem percolate through the porous beds under the western plains. At present the outflow from bores in New South Wales and Queensland amounts to 546,000,000 gallons, which though a very creditable total, bears a very small proportion to the total supply available on the above estimate, and for lack of proper methods

of irrigation much of the water already raised is running to waste when it might be utilised at moderate cost for raising fodder crops. A considerable portion of this excellent volume is taken up in showing how sub-artesian supplies might be utilised, and still more in dealing with the question of irrigation; and these are no doubt the most valuable sections of the book. Sub-artesian water, the author tells us, 'lies as a rule in the sands and gravels and newly-formed rocks of the Post-Tertiary or newest upper formations. A very large portion of the rainfall has sunk into this formation and is lying conserved therein.' A great deal of practical information is given as to how this valuable reserve of water may be utilised, and what are the best methods of discovering it. Australia possesses large areas which will never be put to their fullest or most profitable use till irrigation on a large scale has been successfully accomplished. It is interesting to read that in India alone there were in 1903 no less than 33,000,000 acres irrigated and that the irrigated areas in Egypt, France, Italy, Spain, and the United States bring the total up to 54,500,000 acres of land in these countries alone, which but for irrigation would be barren and unproductive. It is estimated that there are no fewer than 200 millions of persons depending solely for their food upon irrigated areas. Thus the possibilities of Australian development by means of our vast artesian supplies are simply enormous. The value of Mr. Cox's work is greatly enhanced by the numerous appropriate and excellent illustrations it contains, and altogether it deserves to be widely read, studied and recommended by everyone interested in the important subject of which it so ably treats. Messrs. Angus and Robertson are fortunate in their printers. The book is carefully read, the letterpress and illustrations are excellently printed, and the binding is good and serviceable."

THE AUSTRALIAN AGRICULTURIST: "It is a good sign for the future of Australian irrigation when an exhaustive work is produced by an authority with large local experience, and under Australian conditions, for though we have many books of reference on irrigation work they are mainly written from an Indian, Egyptian, or American point of view, and even though the conditions may be fairly equal, there is an inevitable want of confidence where large sums of money may be involved in the outlay. It is an old saying that in Australia things are apt to go by the rule of contrary, and we feel that because a certain cause produced certain results on the other side of the line, that is no certain rule that under our conditions, the

result would be the same. Mr. W. Gibbons Cox, C.E., has issued, after many years of practical irrigation work in Victoria, New South Wales, Queensland, and Western Australia, an exhaustive work on irrigation and land drainage. . . . But though the author deals with the great problems of the artesian areas, as indicating where work may be taken in hand with probability of success, he deals also with questions of machinery and plant, reservoir and ditch making, and the best arrangement of land for irrigation; the use of bore water and its value for stock, woolwashing, and crop purposes. Drainage is another section of the work, which is a valuable addition to our Australian literature on the subject."

Newcastle Morning Herald: "'Irrigation and Land Drainage' is the title of a work by Mr. W. Gibbons Cox, a copy of which comes to hand from the publishers, Messrs. Angus and Robertson, Sydney. Irrigation is the theme of much speaking and many writings, but practical contributions to this important question as it affects Australia are really very few, and Mr. Cox's work, which is largely based on his personal experience, is, therefore, doubly welcome. Special prominence is given to the subject of artesian water, and its use for irrigation. So large a proportion of the rainfall sinks to the artesian and sub-artesian strata, that the utilisation of this source of supply is of great importance, and Mr. Cox gives much practical advice on where and how to sink wells, on the preparation of the ground for irrigation, and the proper methods of applying water. Illustrations are given of irrigated trees and crops in the dry never-never country, and the dissemination of the information should do much to stimulate enterprise. Irrigation from rivers, dams, and by means of windmills, is also fully dealt with, and altogether the author may justly claim that his book fills the proverbial long-felt want."

Sydney Wool and Stock Journal: "The book deals in a most exhaustive manner with artesian and sub-artesian water supplies, and in dealing with irrigation treats of the amount of water supplied, pumping plants, reservoirs, evaporation, ditch making, preparing land and applying the water, arrangement of farm, sub-irrigation, etc., etc. Altogether it is by far the most comprehensive work on this important subject that has yet come under our notice, and should be in the hands of all pastoralists who desire during seasons of plenty to prepare for the times of adversity, which, unfortunately, are bound to recur sooner or later. The book is profusely illustrated with views of

bores, and numerous sketches illustrative of the letterpress and a handy map of the artesian and sub-artesian areas of Australia are included. What with the hints given for the practical carrying out of any work, and the illustration, the book is calculated to turn an ordinary man into a civil engineer, and no one should attempt any irrigating work without having first read up Mr. Cox's advice on the subject."

Sydney Stock and Station Journal: "Here is a book about Australian irrigation, and on page 2 the writer says: 'We have no inland mountain system to help the formation of cyclones, or to deflect monsoonal currents into cooler levels, and so give rise to rainfall.' That is our trouble, in a nutshell. We are short of mountains. If we had a high range, like the Rockies, or the Alleghanies, or the Cordilleras, we'd be all right, for then we'd have big rivers, and a heavy rainfall. But we haven't the mountains, so we have to fall back on other things. We must find wheats—or develop them—which will grow with very little moisture, and we must learn how to use the underground waters of our great continent. This book on irrigation is written by a man with a wide experience, and a varied knowledge. He gives you every side of the problem, and he backs up his statements with facts. He quotes largely from men like Pittman, David, Jack, Russell, and others who have made artesian water their study, and he tells you all that is known, up to date, about the water question from an Australian point of view. Talking about Queensland, Mr. Cox says that: 'The underground water supply of Queensland will be of greater value to the country than all the gold mines that have yet been discovered.' Yes; and he might have added, than all that ever will be discovered. What we want in this country is water, not gold. We need to find wheats which will grow on six inches of rain, far more than we need new gold mines. Mr. Gibbons Cox discusses questions like that of evaporation and kindred subjects in a way that convinces you that our country is not so hopeless as many people think. We need to learn what our artesian supply means, and what it is capable of, and then we need to know how to apply it. All these matters are dealt with in this book of about 300 pages, which is fully illustrated, and not too technical. It is written for the non-scientific man, and will be of immense value to all those who live on the artesian area."

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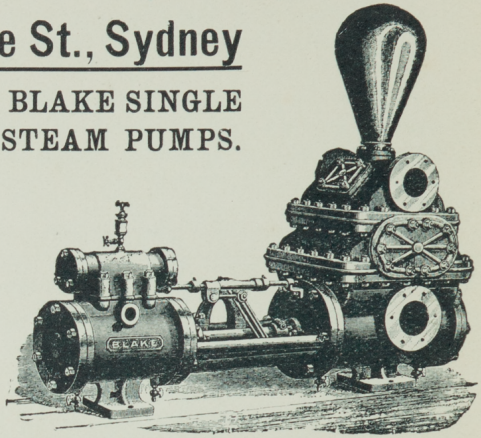

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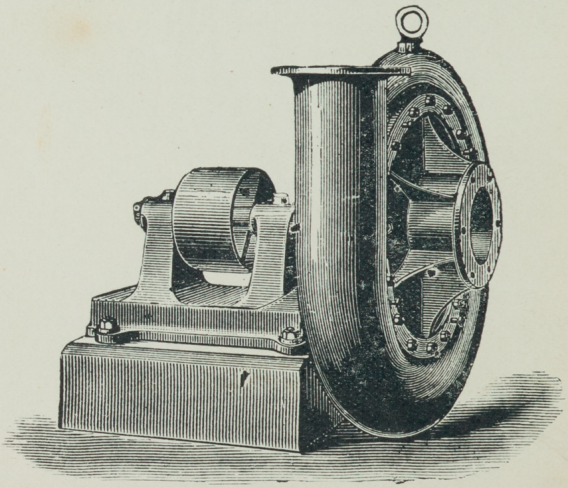

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PREFACE

Irrigation as an aid to the full utilisation of the great natural resources, pastoral and agricultural, of Australia is here discussed.

Vast areas of country, the soil of which is of the highest fertility, become barren and comparatively useless because of their aridity; yet rivers and creeks flow periodically through these vast tracts, and inexhaustible accumulations of water pass beneath their surface. The problem of their irrigation from both these sources is treated fully and practically, according to the latest and most approved methods; and its corollary, land drainage, is also dealt with.

The writer has been continuously engaged for many years in Victoria, New South Wales, Queensland, and Western Australia, in applying and amplifying experience gained in water-supply and irrigation works in the Western States of America and in England.

Government reports, scientific papers, press correspondence, and all other available sources of knowledge have been made use of, but it would be impossible to credit each particular source with the items of information or illustration derived therefrom.

CONTENTS

	Page
Introduction	1
Artesian Water Supply	6
New South Wales	12
Queensland	34
Victoria	50
South Australia and the Northern Territory ...	52
Western Australia	54
Ocean Outlet and Discharge	66
Potential Resources	77
Variation in Flow	83
Conditions Governing Rise of Waters ...	85
Hydraulic Considerations	87
Artesian Bores as Affecting Climate	90
Machinery	91
Sub-Artesian Water Supply	105
Machinery	120
Irrigation	133
Amount of Water Applied	135
Pumping Plant	143
Reservoirs	151
Evaporation	155
Ditch-making	158
Preparing Land and Applying the Water ...	161
Arrangement of Farm	189
Sub-Irrigation	193

Page

Treatment of Alkaline Waters and Lands ... 197

Saltbush and Its Cultivation 215

Results with Bore Water 226

Drainage—

Of Lands 243

Of Farms 250

Appendix—

Mechanical Power from Bores 266

Extra Results Incidental to Boring 274

Statistics of Boring (N.S.W.) 278

Conclusion 288

Index 293

INTRODUCTION

With all its natural wealth and resources, Australia has been subject to one great drawback—that of occasional droughts of greater or less severity. Like most semi-tropical and tropical countries—in themselves among the most prolific in the world—the country is not exempt from occasional periods of extreme aridity. These are mainly due to peculiar meteorological conditions, which may be concisely described as follows:—

The sun's heat within the tropics causes a great uprush of the moisture-laden air there, and not until this air has been largely drained of its moisture does it again sink to earth within the high-pressure area in which Australia is situated. Again, we are situated midway between the great westerly movement of the air in the tropics and the easterly movement in higher latitudes, which give east coasts in the tropics and west coasts in latitudes beyond 40 degrees south a maximum of rainfall. This explains why the extreme north of Australia and the southern coasts of Tasmania and New Zealand, apart from their more insular position, should receive a more regular rainfall than the mainland of Australia, which occupies the neutral zone. Our rainfall is consequently more or less sporadic, and results from depressions monsoonal or artarctic in origin. The flat nature of our inland country still further accentuates our liability

to drought. We have no inland mountain system to help the formation of cyclones, or to deflect monsoonal currents into cooler levels, and so give rise to rainfall. Moisture-laden air may stream in from surrounding oceans, but the more than tropical heat of our inland plains will warm it far above the temperature, or dew point, at which it would part with its moisture and drive it away to more favoured regions. That is the normal experience of Australia. Speaking generally, it may be said that we only get a really useful rainfall when adjacent anti-cyclones evolve sufficient energy. The monsoonal rainfalls have, however, when we do get them, been productive of all the prosperity—partial as it has hitherto been—of which the country can boast; and Nature compensates us for some of our loss by preserving for future use a great part of the rainfall in the water-bearing rocks covered by the rock and earth that prevent evaporation.

Shortly after arriving in Australia, from the United States and England, I witnessed painful evidence of a bad drought, which certainly was never exceeded in intensity by anything of the kind in America although that country is not exempt from disastrous droughts, especially in the great areas of the West lying between the river systems.

It was at a small township and district in Victoria where the drought occurred, and the description of it will apply to other parts of Australia. The natural water supply had become exhausted by use and evaporation, and the live stock were dying, while the women and children were beseeching the conductor of the Government water-train—run for the

use of the line-repairers' camps—to give them water. Along the dried-up beds of creeks and lagoons, miles of bleached bones of dead cattle and sheep lay exposed to view, the line of the watercourses being thus vividly defined. The poor brutes, in their intense sufferings, had ventured for a drink of the last water left, and, sinking down, weak and helpless, had perished in the vain attempt to quench their dying thirst. Overhead a scorching sun was shining like molten brass, and the heat-waves of the atmosphere rendered the eyesight powerless to define objects at a distance, and a telescope only magnified the blurred effects. All vegetation lay withered, except the huge eucalyptus tree, which is provided with a long tap-root, through which moisture is drawn from far below the arid surface, and the tree's vigour maintained. The birds dropped gasping from the trees; emus, travelling as only emus do travel, with sedate, listless steps, passed by in search of water; and the iguanas, with little life left, existing on their anteriorally-acquired vitality—their fat alone—could hardly crawl to a place of safety. The experience of that drought was sufficient to impress the mind, and to enlist the energy of any man, engineer or other, to find a remedy.

The natural sources of water supply in Australia are rainfall, river supply, and the creeks, lagoons, and water-holes of the interior, before soakage and evaporation have exhausted the supply.

Owing to the comparatively low altitude of the existing ranges, the watersheds of Australia are, generally speaking, less effective than those in countries possessing mountain chains. With an equal

rainfall, the tendency to maintain a system of large torrential rivers is lacking. Another condition which is prejudicial to the formation of river systems is the usually absorptive nature of the soil. At flood times, during a small portion of the year, there are long stretches of navigable waters in the interior; but, in times of drought, these rivers and creeks are a name only, because soakage and evaporation, especially soakage—powerful factors in results—have reduced them to a mere chain of water-holes, if indeed they have not disappeared altogether.

The Darling, Murray, and other main rivers afford great volumes of water in flood times, which may be conserved and used for irrigation on a large scale. The frontages of the smaller rivers and watercourses have some value for the pastoral occupant, as they afford an inexpensive though precarious, source of water supply. Back from the frontages artificial supplies are provided by means of excavations and dams. The expensive nature and magnitude of these works render large paddocks indispensable, the object being to make one conservation serve as large an area of country as possible. The disadvantages are apparent, when we consider the concentration of large numbers of stock in their daily journey to and from the water; the contingent expense of attendance; the deterioration of the fleece by reason of dust; the waste and destruction of feed caused by trampling, and of water by stock swimming, and loss by bogging. On the other hand, a well-located bore, with channels carrying the flow for miles through paddocks, materially alters the position, and affords a double frontage,

as it were, to a running stream, superior in many respects to a river; it admits of smaller paddocks which will carry far more stock in proportion to a large paddock served with only one watering-place. The enormous traffic to and from the water is avoided, and the dust and waste of feed is consequently reduced to a minimum. Nor do the stock require the same attention, for the risk of bogging of weak animals is entirely removed. What the presence of water running through a paddock means to lambing sheep, pastoralists will realise without explanation. It is a fair estimate that a paddock so watered will carry 20 per cent. more sheep at a less cost, than under the first-described conditions. The rainfall of the interior is but small, and averages in most of it about 12 inches in the year; and, even after extensive water improvements are effected, taking season with season, the country will not carry with safety more than a sheep to eight or ten acres. To those acquainted with stock-raising in more favoured lands, this fact will show clearly enough how dry the country is. The country, although generally flat, slopes somewhat from East to West.

ARTESIAN WATER SUPPLY

DEFINITION OF ARTESIAN WATER.

An artesian well is a shaft bored through impermeable strata until a water-bearing stratum is reached when the water is forced upwards by means of the hydrostatic pressure due to the higher level at which the main, or supply, water was received. The action of an artesian well depends upon very simple principles. The water accumulates, and is conserved, in porous rocks and ground lying between two layers of impermeable strata forming, in the artesian rocks of Australia, a half-basin (see Fig. 1., p. 73). These porous rocks crop out at the surface, and form thereby the means of intercepting, on the higher levels or outskirts of the basin, the rain and flood waters which sink into them. Becoming surcharged with this water, any boring which is made from the surface into the water-bearing rock will, at greater or lesser depths, intercept this water, which, from the hydrostatic pressure of that part of the accumulated water above the level of the surface of the ground at the site of the boring, will rise above the surface approximately to the highest level at which the accumulated water stands. Undulation, or difference in the level of the surface, will give a flowing well in one part of a station and a non-flowing well in another part, the water in both of which is derived from the same artesian source.

A simple illustration is given by taking a glass tube of the form of the letter U. If water be put into this tube, it will stand at the same level in both arms, and if a third tube be connected with it, between the two arms, the water will rise in it, and sink in the other two, until equilibrium is restored. The laws upon which the action of an artesian well is regulated are therefore as follows:—(1) The orifice of the bore must be below the outcrop of the water-bearing stratum. (2) The water must be contained between two impervious strata.* (3) The strata must take the form of a basin or half-basin, or the outflow must be so far impeded as to keep the water at an elevation higher than the orifice of the bore. Cases have occurred in the United States where "flowing" wells of little pressure have become non-flowing ones, and in previously " non-flowing " wells in the same district the water has afterwards overflown the surface. In Australia it is a common practice, where the water has risen to within a few feet of the surface, to cut a channel to lower ground, and thus produce a "flowing," or non-pumping, well.

The following statement of some Australian bores will show that an overflowing well may be obtained at a very moderate depth, and that, on the other hand wells of great depth may not afford a flow:—

	Bore No.	Depth in feet.	Yield per diem in gallons.	Remarks.
Manfred Downs	1	177	22,000	Overflowing
,, ,,	5	200	20,000	Not overflowing, supply pumped
,, ,,	6	98	16,000	Overflowing

* There is an apparent exception to this. See page 56, Western Australia.

	Bore No.	Depth in feet.	Yield per diem in gallons.	Remarks.
Thurulgoona	2	1,440	30,000	Overflowing slightly, supply pumped
,,	4	718	36,000	Supply pumped
Uanda ...	6	296	40,000	Water rises to within 35 feet of surface

The waters of these bores are undoubtedly derived from true artesian sources.

THE WATER-BEARING ROCKS OF AUSTRALIA.

The following particulars are taken from the latest Geological and other Government Reports of the various States. The map at the end of the volume shows the whole artesian and sub-artesian areas.

The Main Artesian Basin of Australia.—According to Mr. E. F. Pittman, Government Geologist of New South Wales, the main artesian basin of Australia lies chiefly in Queensland, extending—as shown in the accompanying map — on the S.W. into South Australia, and towards the S.E. and S. into New South Wales. Commencing at the Gulf of Carpentaria, and taking in the great part of Cape York Peninsula, it trends southerly, and follows approximately, as regards its eastern boundary, the outline of the adjoining coast, the distance between its eastern margin and the coast varying from about 100 to 300 miles.* Its southernmost development in New South Wales

* This remark applies to that portion of the basin which has proved to be productive of artesian water. But the Triassic rocks (which usually form the storage beds of artesian water in New South Wales) extend from near Toowoomba in an easterly and southerly direction to the coast connecting with the Clarence basin. All bores, how-

is in the neighbourhood of Dubbo, and it extends from there N.W. up the Bogan River to its junction with the Darling, and thence westward along the Darling River to near Bourke; from Bourke W.S.W. to near White Cliffs, and then its boundary follows an irregular course westerly to the South Australian border and across South Australia, just north of Lake Torrens, to about the 133° meridian of E. longitude. Thence it is bounded on the west by an irregular line, based at present on meagre data, following approximately this meridian northwards to its intersection with the 25th parallel of S. latitude; then it trends north-easterly to a point in about long. 141° 30′ E., and about 22° S. lat.; thence its course is north-westerly to near the mouth of the Roper River, in the Gulf of Carpentaria. The area whose boundaries have thus been roughly outlined is proved by the palæontological evidence to have been first chiefly a vast freshwater lake, and subsequently, for the most part, an inland extension of the Gulf of Carpentaria, expanding southwards into a Mediterranean. The deposits of these lakes and seas, subsequently uplifted, constitute the present main artesian basin. The artesian-water-bearing area is thus apparently surrounded by older impervious rocks, with the exception of its northern extremity, which meets the sea at the Gulf of Carpentaria.

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ever, put down in this extension east of Toowoomba have hitherto proved unproductive. Dr. R. L. Jack, late Government Geologist of Queensland, is of opinion that there may be a concealed ridge of Gympie (Carboniferous) rock cutting off the Clarence and Brisbane Trias from the main artesian area.

It was formerly supposed that the recurrence of artesian water was practically confined to the beds of the Lower Cretaceous formation, but Mr. Pittman says: "There is a possibility of the Triassic, or Jurassic, formation being continuous (underneath Lower Cretaceous) between Eastern Australia and Leigh's Creek in South Australia, and it is not improbable that the porous strata of this formation may constitute the chief storage beds of the artesian water supply of Australia."

The lithological evidence obtained from the Roma and Dalby (Queensland) bores shows a decided similarity to that afforded by the Racecourse and Laidley (Queensland) bores, which are known to be sunk in the Ipswich Coal Measures. It seems, therefore, that the Roma bore, after passing through the Lower Cretaceous formation, entered the older rocks — the Triassic Ipswich Coal Measures. The emanation of natural gas from the bore seems to give additional proof of this view.

The Queensland Racecourse, Laidley, and Dalby bores have all yielded artesian water, and many borings in New South Wales, undoubtedly drilled in coal formations—the equivalent of the Ipswich beds—have struck large artesian supplies. It seems quite clear that in Australia — just as in Kansas, Nebraska, and Texas, where the carboniferous sandstones of the Triassic formation yield artesian water—large flows of artesian water may be obtained from the Ipswich Coal Measures; and this is a matter of great importance to Australia, for there is good reason for believing that the Triassic, or Jurassic, Coal Measures may be continuous under the Lower Cre-

taceous beds. If such be the case, it is clear that a large area hitherto regarded as Lower Cretaceous is, in reality occupied by rocks of Triassic or Jurassic age, and that the yield of artesian water from some of the existing borings has been reinforced to a great extent from strata of whose water-bearing possibilities we had no previous knowledge.

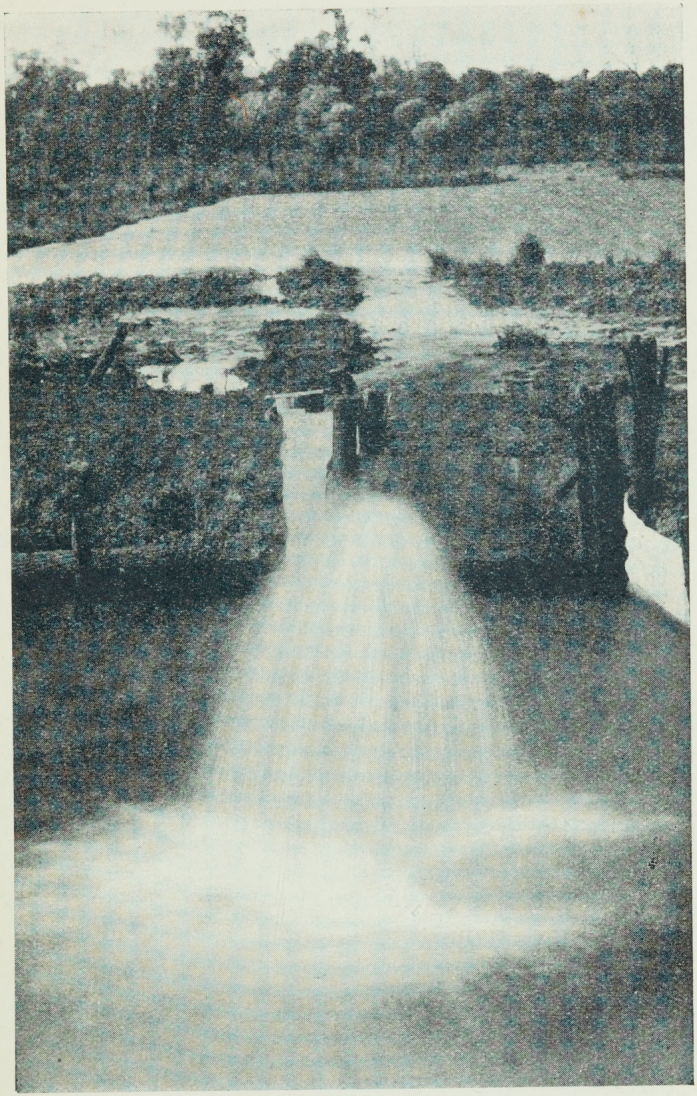
As regards its surface configuration, the artesian area is, for the most part, a series of almost level plains and gently-undulating downs. In New South Wales the surface is largely formed of plains so nearly level that any inclination is quite imperceptible to the eye, being not more than two feet per mile. This is due to the deposits from the flood waters of the Darling River and its tributaries. The only exceptions to this general rule are (1) the intake beds, which attain altitudes of at least 1,200 feet along its eastern margin and form hilly to mountainous country along the western flanks of the Main Dividing Range, and (2) the inliers of palæozoic sediment and igneous rocks, such as Mount Browne, Mount Foster, and Tibooburra. These inliers formed islands in the Triassic lakes and Cretaceous seas during the deposition of their respective sediments and outliers of desert sandstone (Upper Cretaceous). These cappings are mostly met in the north-west corner of New South Wales. Over a considerable area they form low, isolated hills, rising to not more than 20 feet or 30 feet above the general level of the surrounding country, but in places they attain to larger dimensions—up to 500 feet. For the most part they rest on the Triassic, or Cretaceous, rocks of the artesian area, but occasionally, as at Mounts Oxley and Poole, they repose on palæozoic rocks.

NEW SOUTH WALES.

The Government Geologist, Mr. E. F. Pittman, and Professor T. W. E. David, in a joint paper, have described the geology and physiography of the artesian areas as follows*:—

The State may be divided into three portions: (1) The coastal plains and eastern foothills of the Main Dividing Range; (2) the Main Dividing Range; (3) the western foothills of the Dividing Range and the western plains. With regard to (1), the rainfall over this area ranges from 24½ inches near Scone to 81 inches at Byron Bay per annum, the average of the whole area being about 43 inches per annum. This, in ordinary seasons, is ample for the requirements of pastoral, agricultural, and fruit-growing industries. The question, therefore, of irrigation in this division is not of paramount importance except in isolated areas, where river water might be utilised for the purpose, as has been done at Mulgoa, near Penrith. With reference to the possibility of the occurrence of artesian water in this division, its geological structure may be summarised as follows: From the Macpherson Range, on the border of Queensland, down to about 30 miles south of Grafton, there is a basin-shaped extension of the Ipswich Coal Measures of Queensland, known as the Clarence Basin. It consists of sandstones, shales, and interbedded coal seams of Triassic Age, as is proved by the occurrence in them of the fossil *Tœniopteris Daintreei*. As these beds are the equivalents of the artesian-water strata, to be described presently, the

* Proc. Roy. Soc. of N. S. Wales, vol. xxxvii., page 103.

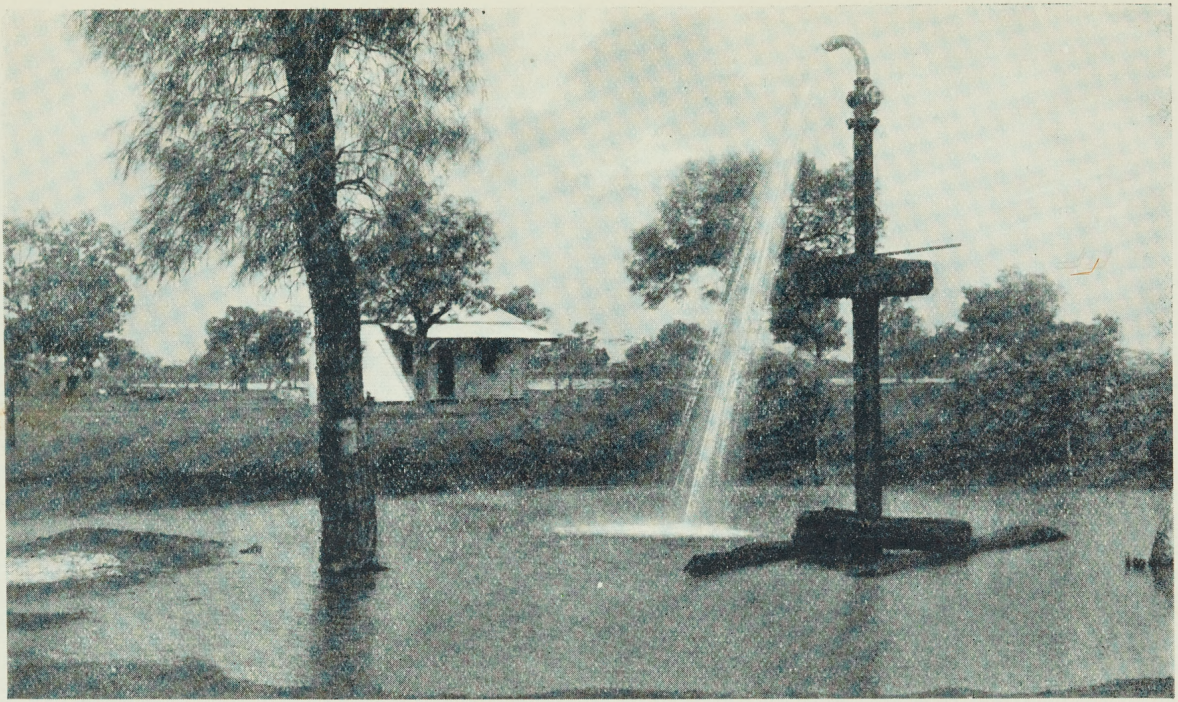


Weilmoringle Bore, New South Wales. Depth, 1,590 feet; flow, 1,756,000 gallons per diem; temperature, 98 degrees Fah.

question as to whether or not they contain artesian water is of considerable importance. A bore has been put down with a view of testing the question to a depth of over 4,000 feet at the Racecourse, Grafton, but was finally abandoned owing to mechanical difficulties. Palæozoic rocks were not met with, and the test is, therefore, an incomplete one so far as the question of artesian water is concerned. It is possible, however, that the bore may have penetrated Permo-Carboniferous rocks, as is suggested by the fact that at a depth of 3,100 feet a strong supply of natural gas was met with, and, hitherto, no authentic case of an emanation of such gas has been met with in any strata of New South Wales except those of the Permo-Carboniferous system. From the southern extremity of the Clarence Basin to Port Stephens the rocks are chiefly Carboniferous, with some Devonian, and are impervious to water.

From Port Stephens to as far south as Ulladulla stretches the Permo-Carboniferous coal basin, a large portion of which is overlaid by Triassic rocks. They have been tested in numerous places by bores, and lately by the Sydney Harbour Collieries Co.'s staff at Balmain, which penetrated these rocks to a depth of 2,900 feet, and have been proved to be entirely devoid of artesian water. From Ulladulla to the Victorian border at the Australian Alps, the strata are formed chiefly of Devonian rocks and intrusive granites, both of which are impervious to water.

(2) The Main Dividing Range.—This range is composed chiefly of Palæozoic and granitic rocks throughout its entire length, with the exception of the central portion, where the deep Permo-Car-



Walkden's Bore, New South Wales. Depth, 1,604 feet; flow, 200,000 gallons per diem.

boniferous basin, overlaid by Triassic rocks, crosses it obliquely in a general N.N.W. direction. The portion lying to the north of this basin is known as the New England Tableland, while that to the south comprises the mountainous country extending from Gulgong to the Bathurst Plains, the Monaro Tableland, and Australian Alps. In the last mentioned the Main Dividing Range attains its greatest elevation, about 7,328 feet, at Mount Kosciusko. Its altitude elsewhere varies from about 2,000 feet up to about 4,000 feet. It has the character of a wide and deeply denuded fold-range. In the southern massif the cores of the oldest rocks are chiefly granites, intruding in succession Lower Silurian, Upper Silurian, Devonian, and Carboniferous rocks; while the northern massif (the New England Tableland) is formed of Carboniferous and Devonian rocks, intruded by granites, porphyries, and serpentines.

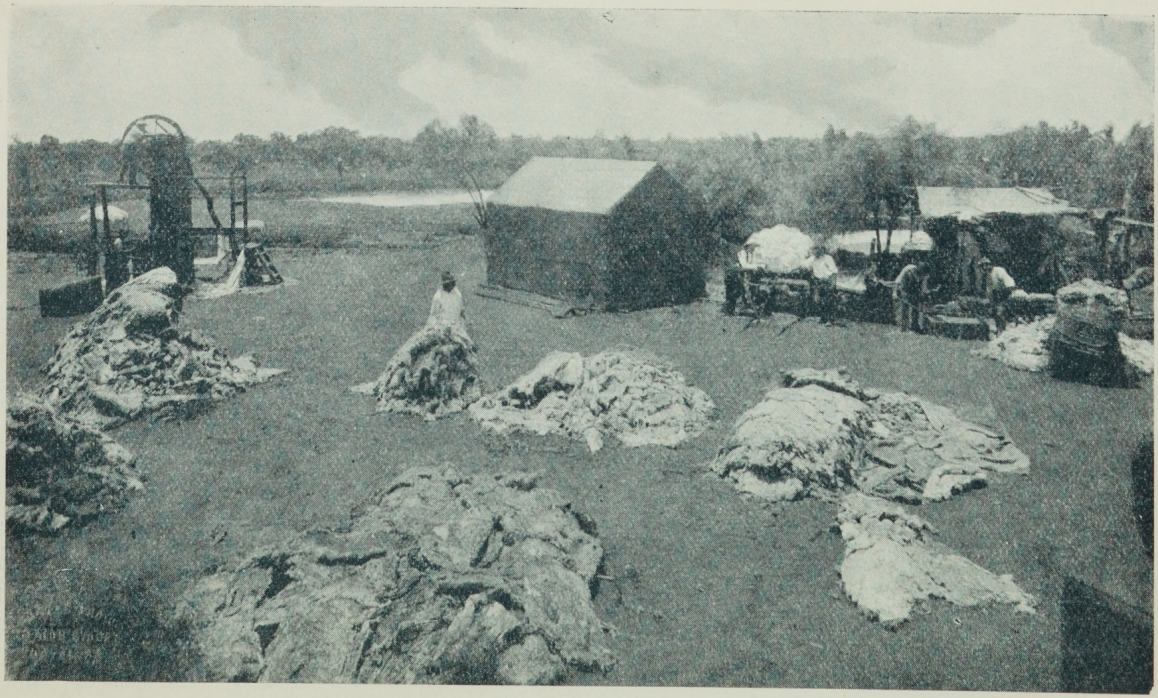
The enormous amount of denudation to which this Dividing Range has been subjected may be inferred from the fact that, if the great anticlines of Silurian and Devonian rocks were restored over some of the granite areas, like those of Bathurst, they would constitute an immense range of Alpine proportions. The material removed by this prolonged erosion has partly been carried eastwards to form the Post-Carboniferous strata of the coastal area, and partly westwards to form the Triassic, Cretaceous, and Cainozoic deposits of the Western Plains. The diversity of rock material which has thus been furnished has resulted in the formation of soils eminently suitable for agricultural purposes, provided a sufficiency of water were available. The rainfall of the Main Dividing

Range varies from 23 inches at Olinda to 83.8 at Condong. The rocks composing this range are impervious to water.

(3) The Western Foothills of the Dividing Range and Western Plains.—A considerable portion of the western flanks of the Dividing Range, from near Texas on the Queensland border to the neighbourhood of Dubbo, are composed of the Triassic rocks. These consist of sandstones, shales, and thin seams of coal (a continuation of the Ipswich Coal Measures of Queensland). Some of the sandstones are of an extremely porous character, and these constitute the intake beds of the artesian water area. They attain altitudes of, at least, 1,200 feet, and have a gentle dip towards the west and north-west. Of the rainfall of the western slopes of the Dividing Range, a portion is lost by evaporation; a further portion is absorbed where it falls upon the porous rocks,* and the balance enters the tributaries of the Darling. As most of these tributaries cross the intake beds, a considerable portion of the water which they carry soaks into the intake beds beneath their channels, so it is easy to account for the fact first pointed out by Mr. H. C. Russell (the late Government Astronomer) that the annual discharge of the river Darling at Bourke only amounted to 1.46 per cent. of the total rainfall within the drainage area.

Western Plains.—If a line be drawn from Nevertire through Moree to Mungundi, it approximately represents the eastern boundary of the plain country, which may be termed the artesian water area. From

* See page 77.—"Potential Artesian Resources."



Eungonia Bore, New South Wales. Wool-Scouring.

(Kerry & Co., Photo.)

Nevertire it is bounded by the Bogan River towards Bourke, thence in a general W.S.W. direction by a line from Bourke towards White Cliffs, and thence by an irregular line, in a general westerly direction, to the South Australian border. From the boundary just described the artesian water area extends northwards and westwards into Queensland and South Australia.

The rainfall over this area varies from about 9 inches on the extreme west to about 22 inches on the east. The fall of these plains is in a westerly to north-westerly direction, at an average rate of about 2 feet per mile. With this very small amount of fall in their channels, the tributaries of the Darling in New South Wales, where they cross the western plains are little more than canals in good seasons and a chain of waterholes in dry seasons. In times of flood, however, these rivers overflow their banks and inundate the surrounding plains for a great many miles.

Details of New South Wales Artesian Area.—*Deposits overlying the storage beds.* The uppermost and newest of these are, more or less, loose incoherent deposits, which may be classed as follows:—

Flood loams and soils.

Red soils.

Sandhills and claypans.

Mound springs or mud springs.

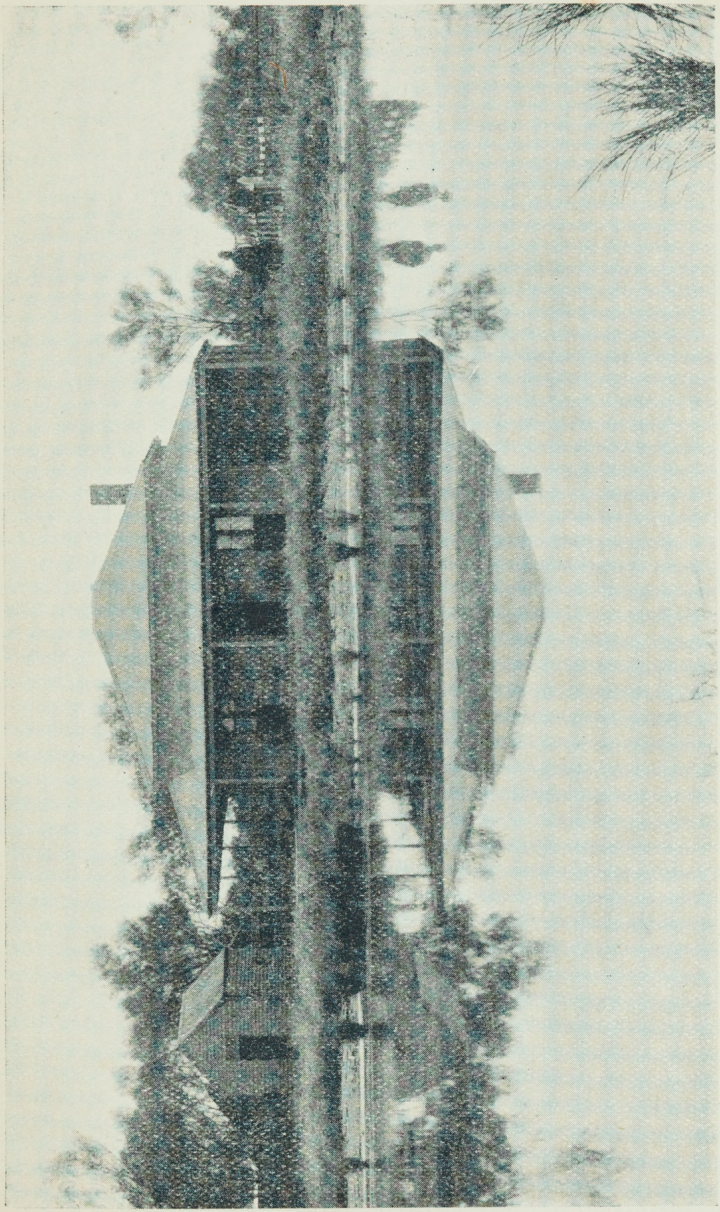
Lower Cretaceous (Rolling Downs formation of (Queensland) shales, marls, and limestone.

Flood Loams and Black Soils.—These form the surface of the plains for a considerable distance along the course of the Darling River and its tributaries.

and have been deposited from the waters of these rivers during flood time. They are composed of the material derived from the denudation of the various kinds of rocks traversed by these rivers, and decomposed basalt probably enters largely into their composition. They are of a bluish-grey colour and strongly plastic in character when wet, forming a serious impediment to travellers. When dry, the material becomes easily pulverised, but forms a good road.

Black Soils.—These are more tenacious than the flood loams, and are typically developed at Moree, where they are largely made of decomposed basalt. Lower down the Darling the soil is not so dark in colour, and merges into the flood loam. With a fair amount of rain it is an extremely fertile soil, much more so than the red soil, but owing to its stiff clayey nature it is much more difficult to work. After light rainfall, this soil, on account of its extreme tenacity, is even more difficult to travel over than the flood loam country.

Mound Springs or Mud Springs.—These have been described by E. F. Pittman in "The Mineral Resources of New South Wales" as follows:—The mound or mud springs are literally springs of liquid mud, which, by overflowing at the surface, have gradually built up conical mounds, which, in New South Wales, are from a few feet to 50 feet or more in diameter, and up to about 15 feet in height. In South Australia Mr. H. Y. L. Brown, Government Geologist, has described some mound springs which attain a maximum height of about 50 feet. The material consists of yellowish clay, whitened in places

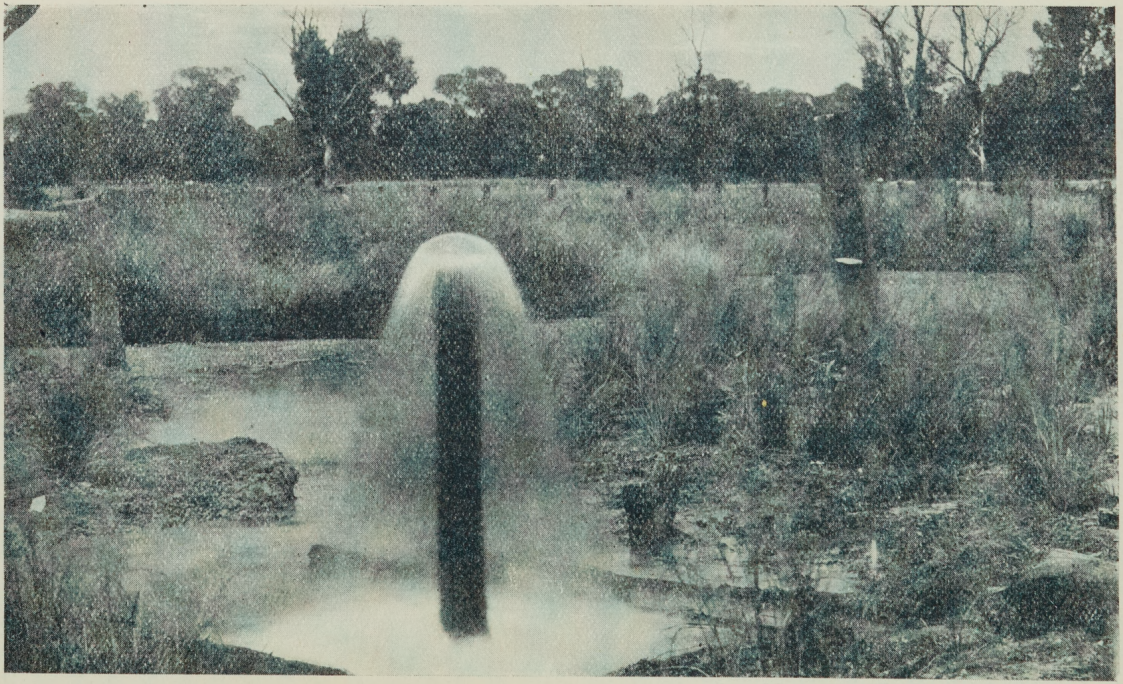


Station Homestead, Cuttabulla, New South Wales. Artesian Lake in foreground.
(Kerry & Co., Photo.)

by calcareous incrustations. A noteworthy feature is the occurrence in this clay of waterworn pebbles of quartz. In Queensland, in the mound springs described by Mr. E. Palmer on the Lower Flinders River, the water is stated to evolve innumerable bubbles of carbonic acid. As regards their distribution, an important characteristic is the fact that they usually occur in proximity to the junction between the older rocks and those of the artesian-water-bearing series; in other words, they are found adjacent to the edges of the basin, or to the edges of the inliers of older rocks which at one time formed islands in the Triassic lake and Cretaceous seas. The experience has been that bores put down for artesian water near these mud springs have invariably yielded a much smaller flow than those situated at greater distances from the margin of the basin. It may also be mentioned that when bores have been made near mound springs, and have struck supplies of artesian water, as the result of the diminution of the pressure caused by the bore the waters have ceased to flow from the adjoining springs. This has noticeably been the case at the Officer Brothers' Bores at Kilara. In cases where observations have been made as to the temperature of the liquid mud flowing from the mound springs, as in Queensland, records as high as from 120° Fah. have been obtained, as, for instance, at Mount Browne, on the Lower Flinders. As the mean surface temperature of that locality is considerably lower than this, it is obvious that the liquid mud in such cases must come from some depth. This consideration, taken in conjunction with the fact already stated, that flows from artesian bores dry

the mud springs in the vicinity, proves that the source of the springs is to be found in the artesian wells water-bearing strata. The mud springs are, in fact, natural artesian wells, where the water, under pressure from the storage beds below, forces its way to the surface through the overlying clayey beds where they are thinnest and therefore offer least resistance. As might be expected, these conditions are found near the margins of the basin, in proximity to the older rocks; for there the upper beds of the artesian series, which are usually impervious clay, become more sandy, and therefore more porous, in accordance with the well-known rule that sediments become coarser the nearer they are to the parent rocks from which they have been derived.

Desert Sandstone.—This formation is of Upper Cretaceous Age, and extends as far south as Bidura near Balranald. Northwards it extends into Queensland, westwards into South Australia, and south-eastwards it extends up to, or even considerably beyond, the limits of the artesian basin. It does not follow, therefore, that the formations underlying Desert Sandstone areas always belong to the artesian series, as in many cases the Desert Sandstone rests immediately upon the older rocks. Owing to the great denudation which this formation has undergone, it does not extend continuously over the areas just described, but occurs as isolated and, generally, low hills or ranges. These in New South Wales occasionally attain a height above the surrounding plains of 500 feet, and a maximum altitude of about 900 feet above the sea, as at Mount Poole in the Grey Ranges. The higher hills frequently exhibit steep



Bundaleer Bore, New South Wales. Depth, 1,612 feet; flow, 184,000 gallons per diem; temperature, 119 degrees Fah.

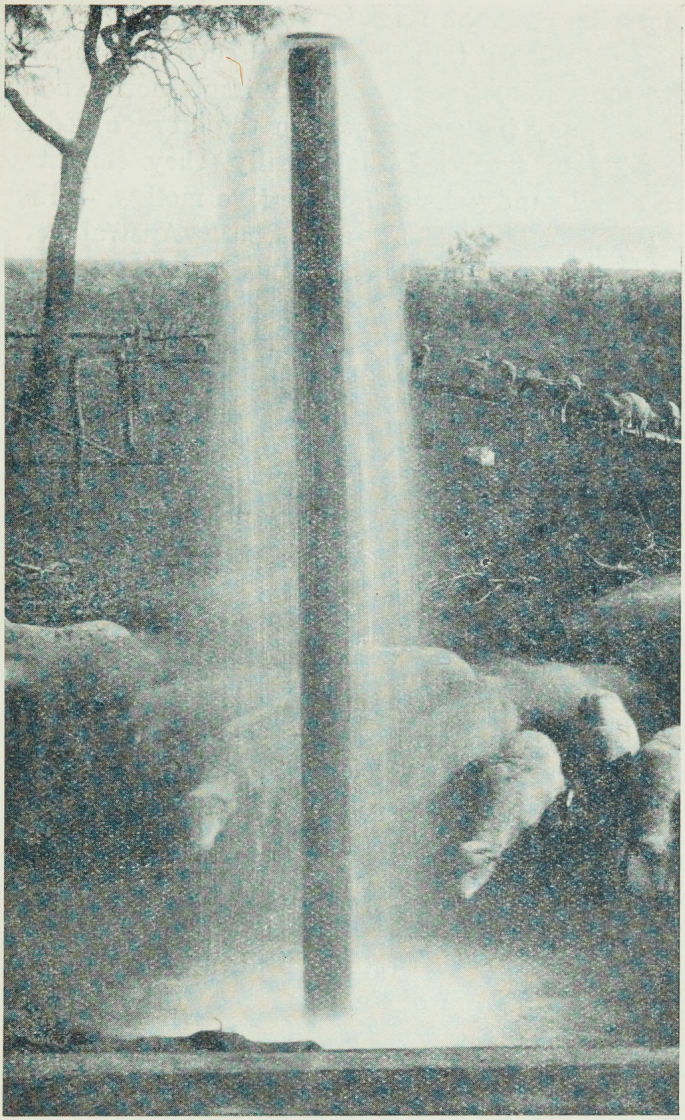
(Kerry & Co., Photo.)

escarpments, the beds being horizontal, or nearly so, and having vertical joints. The beds consist of conglomerates, sandstones, and porcellanites, and a very fine-grained white siliceous rock, having much the appearance of kaolin in general character. Occasionally the sandstones and porcellanites are very ferruginous, and it is thought that these beds have contributed largely to the material of which the red soils are formed. The porcellanised portions are impervious to water, but some of the sandstones are very porous, and it is conceivable that, as pointed out by Dr. Jack, where they overlie the intake beds, they may act as feeders to the artesian supply.

Rolling Downs Formation.—This formation, though proved by the artesian bores to have an extensive development in New South Wales, does not outcrop at the surface, with the exception, perhaps, of the marly clays seen in the north bank of the Darling at the bridge above Bourke. At about 20 miles west of Depot Glen, near Mount Poole, the spoil heaps of some shallow wells show marine fossils of Lower Cretaceous age, proving that that formation comes very close to the surface at this point.

The evidence given by bores made in the Moree district throws light upon the disputed question as to whether the Lower Cretaceous (the Blythesdale Braystones of Queensland) or the underlying sandstons of Triassic age form the true intake beds of the artesian aras. At Bulyeroi (Moree district) the Lower Cretaceous rocks were penetrated to a depth of 520 feet, and at 175 feet from the surface a very small supply of sub-artesian water was met with. Below 520 feet, Triassic rocks, with characteristic plant

remains, were struck, and in them, at a depth of 1,386 feet from the surface, the first supply of artesian water was found, equal to 6,000 gallons per diem. At a depth of 2,370 feet the flow had increased to 1,750,000 gallons per diem. At Wallon Bore the Lower Cretaceous rocks extended to a depth of 1,500 feet from the surface, and they yielded characteristic marine fossils. No water was obtained in these beds. At 1,630 feet the characteristic Triassic fossil *Tœniopteris Daintreei* was recognised, and a coal seam, 15 inches thick, was intercepted at a depth of 1,650 feet The first artesian water, flowing at the rate of 400 gallons per diem, was not met with until the bore had reached a depth of 2,330 feet—that is, well into the Triassic Coal Measures. As the boring progressed below this depth, the flow of water continued to increase until it reached its maximum of 800,000 gallons per diem at a depth of 3,560 feet. This evidence is conclusive, and proves that in New South Wales, at any rate, the Triassic sandstones, and not the Blythesdale Braystones, form the storage beds of the artesian areas. Moreover, it is doubtful whether the Blythesdale Braystones extend into New South Wales territory, as nothing resembling it was recognised at the base of the Cretaceous rocks in either the Bulyeroi or Wallon bores. The respective levels of the base of the Cretaceous formation in these bores show that the bed of the Cretaceous Sea dipped rapidly northwards from Moree into Queensland. It is probable, therefore, that the Blythesdale Braystones of Queensland may have thinned out against a sloping surface of Triassic rock in the direction of the New South Wales border. It may, therefore, act as a feeder to the



Glengarie Bore, Glengarie, New South Wales. Depth, 1,369 feet; flow, 250,000 gallons per diem.

(Kerry & Co., Photo.)

underlying rocks of Triassic age. It is obvious from the facts adduced that the Lower Cretaceous rocks of New South Wales are essentially impervious, and do not form any important part in the storage beds of the artesian area. Lithologically, they consist of marly and sandy shales and marine molluscan limestones. In Queensland and South Australia the sandy shales and limestones of this formation contain abundant foraminifera, with occasional infusoria and diatoms, but only a few microzoa of this kind have been observed in the rocks of this age in New South Wales. Although there may be local evidence of thinning out of the basal beds of the Lower Cretaceous against the Triassic strata in New South Wales, no distinct evidence has been obtained in this State as to there being any unconformity between the two formations. It should be mentioned that the Queensland geologists state that they have observed such unconformity in parts of their territory, but their descriptions leave it an open question as to how far the phenomenon recorded may be due to contemporaneous erosion rather than to unconformity.

The Intake Beds.—The intake beds consist of porous freshwater sandstones of the Triassic series. These beds extend into New South Wales from Queensland, and are first seen on the Dumaresq River at a point 15 miles west of the township of Texas. The eastern margin of the intake beds in New South Wales can be traced thence in a S.S.W. direction as far as Dubbo. As already stated, they form part of the western flanks of the Dividing Range. They have an average width of probably 60 miles. They dip gently westwards, and it is believed that they

are continuous under the Cretaceous rocks for the whole width, at least, of the portion of the artesian area which lies in this State. For example, at Salisbury Downs, west of Wanaaring, the characteristic Triassic fossil *Tæniopteris Daintreei* was obtained from near the bottom of the bore. This point is about 400 miles west of the eastern boundary of the intake beds. The series consists of shales, sandstones, and coal seams, and their aggregate thickness in places (as, for example, at the Wallon and Bulyeroi bores) is at least 2,000 feet; but of this thickness only a small portion is made up of the porous beds which occur at intervals in the series. In places the intake beds are of a very porous character, as, for example, near Wallangra and between Yetman and Texas. In the last-named area the sandstones have undergone considerable disintegration, giving rise to a thick superficial covering of sand, about 20 miles in width. As regards altitude, the intake beds attain an elevation of about 1,200 feet above sea level between Yetman and Texas. At Black Jack and Curlewis, near Gunnedah, their height above sea level is respectively about 1,670 feet and 1,730 feet and at Narrabri and Rocky Creek about 2,250 feet.

Thickness of Porous Beds as Proved in Bores.—At the Bulyeroi Bore (about 60 miles S.W. of Moree) artesian water was first struck at a depth of 1,386 feet in a bed of porous sandstone 160 feet thick. A fresh supply was struck at 1,896½ feet, and from here to a depth at which the bed rock was struck—viz., 2,370 feet—the flow continued to increase, amounting to a total finally of 1,750,000 gallons per diem. Of the strata between the levels of 1,896½ feet and 2,370

Orchard, Barrungun Bore, New South Wales.

(Kerry & Co., Photo.)

feet only about 30 feet were shales, the remainder being sandstones, with a thin band of conglomerate. In this case, the lower division of the porous beds has, therefore, a thickness of about 444 feet, and if to this be added 160 feet of porous rock in the upper division, the total thickness of porous beds belonging to the Triassic formation at this bore amounts to about 600 feet. The Bulyeroi Bore bottomed on bed rock.

At Woolabra Bore, between Narrabri and Moree, the first water-bearing strata were struck at 930 feet, and proved to be about 35 feet thick; the next were struck at 1,125 feet, and proved to be about 60 feet thick; the next at 1,209 feet, thickness about 180 feet, which makes a total thickness of porous strata in this bore of 285 feet. Bore bottomed on bed rock.

The following is a summary of ascertained thickness of porous beds:—

		Yield in gallons per diem.
Bulyeroi Bore	520 feet ..	1,750,000
Woolabra Bore	285 feet ..	417,000
Tenandra Bore	150 feet ..	1,200,000
Warren Bore	142 feet ..	1,000,000
Carinda Bore	42 feet ..	1,000,000
Kenmore Bore	160 feet ..	2,050,000
Mooramina Bore	154 feet ..	1,069,920
Wilby-Wilby Bore	66 feet ..	1,114,000
Tulloona Bore	584 feet ..	648,864

For the purposes of the calculations made hereafter the mean thickness of the porous strata underlying the artesian area of New South Wales is taken at 300 feet.

The Impervious Rocks underlying the Storage Beds.—A knowledge of these has been obtained from studying the chips of rock resulting from the drilling

operations, and in part their nature may be inferred from the character of the rocks forming the rim of the artesian area. As regards the latter, the eastern rim of the basin, where it touches the Queensland border, consists of granite. Further south it is formed chiefly of Carboniferous rocks to near Narrabri. Thence to the Warrumbungle Ranges the bed rock is partly Carboniferous, with occasional granite areas and older sedimentary rocks. Thence as far as Dubbo, and for about 12 miles in a south-westerly direction, the bed rocks are Silurian and Devonian slates, limestonse, and quartzites, with granite, followed by a synclinal trough of Devonian sandstone, which extends southwards past Bogan Gate, the width of the trough being about 20 miles. The rocks hitherto described, with the exception of this Devonian trough and the Permo-Carboniferous strata of Ballimore, are all impervious. The sandstones, however, of the Devonian are—at any rate, at the surface—of a porous character, and in view of their occupying a synclinal fold which abuts against, and probably underlies, the southernmost portion of the artesian area, there seems to be a possibility of this also being water-bearing.

Artesian wells are not, at present, much distributed over that part of the artesian area which lies between the Culgoa River on the east and the Paroo River on the west. A very large proportion of the bores put down by the pastoralists, as distinct from those made by the Government, lie within the above area. By far the greater number of the bores in this area have succeeded in striking artesian water. The failures have proved most numerous on the southern portion where it approaches the Darling River, and amount

Irrigation Farm, Native-Dog Bore, New South Wales.

(*Kerry & Co., Photo.*)

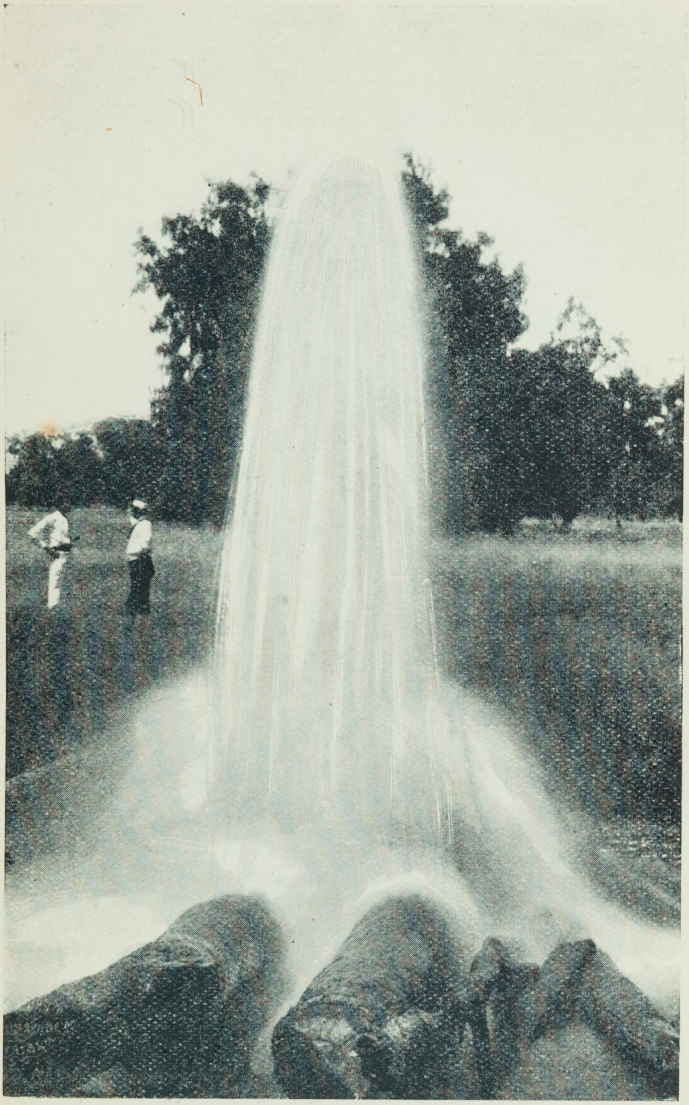
to about 11 per cent. of the total bores made in the State. The deepest part of the artesian basin, and that which also yields the largest flows of water, lies within the area between Brewarrina, Dubbo, and Yetman.*

QUEENSLAND.

To assert that the underground water supply of Queensland will be of greater value to the country than all the gold mines that have yet been discovered may startle many who have not yet studied the subject. Yet such is the indubitable fact. The discovery of artesian water has already saved stock to the value of hundreds of thousands of pounds, and when the immense water-bearing areas—more than half the State—hitherto subject to drought, have been further tapped by boring, the saving in future years, when systematic irrigation for fodder crops becomes general, will amount to millions more, and at the same time make agricultural pursuits profitable in districts where the scanty rainfall now renders them too precarious to be thought of.

The presence and plentifulness of artesian water depends on the rainfall in the higher regions, on the lower altitude of the bore site, and on the permeable character of the rocks below. The territory of Queensland is in an exceptionally favourable position for the fulfilment of these conditions. The rainfall, on which most of its artesian water depends, is

* See "The Mineral Resources of New South Wales," by E. F. Pittman.



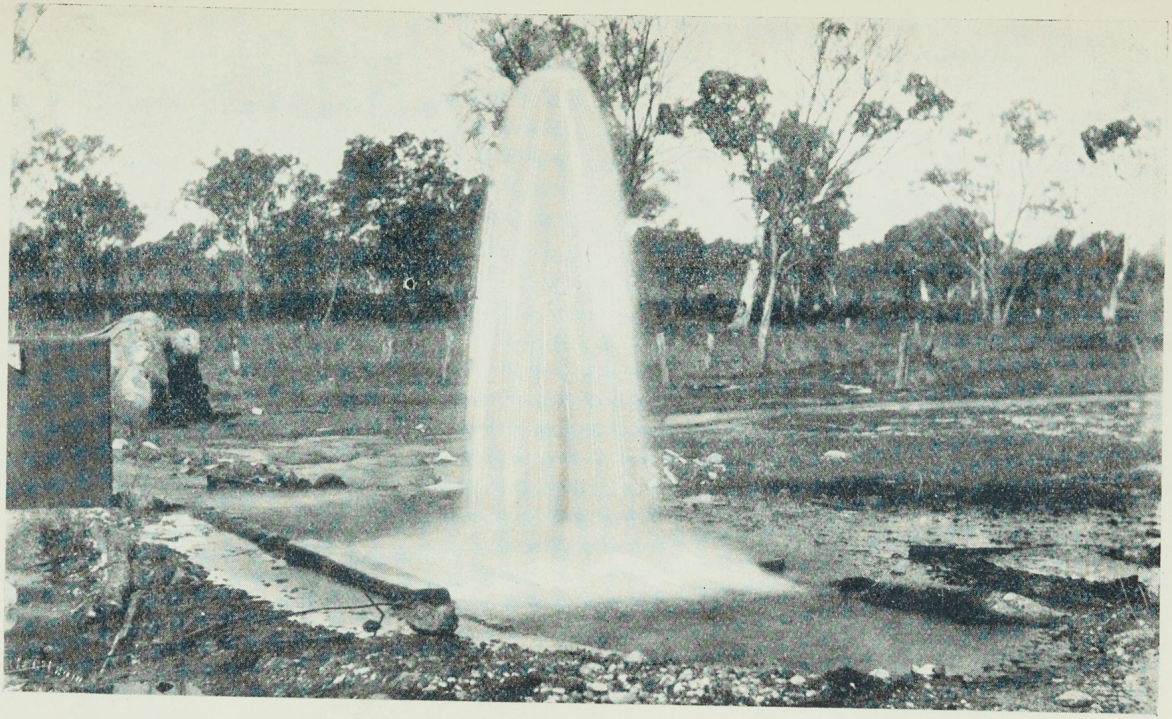
Thurulgoonah Bore, Queensland. Depth, 1,710 feet; flow, 3,000,000 gallons per diem.

(Kerry & Co., Photo.)

caught on the western slopes of the Dividing Range, from which almost the entire country to the border trends downward. It is not because the rainfall is so scant that the western river system runs dry half the year, but because so much of it sinks into the ground. Then the formation of rock most favourable for the subterranean carriage of water—the Lower Cretaceous—is the prevailing formation under the whole of the wide-stretching Western Downs, embracing an area, (according to recent calculations of the Geological Department) of 376,000 square miles, or more than 56 per cent. of the total area of the State—namely, 668,497 square miles. A fact like this opens up vast possibilities for the future. With the exception of the famous Dakota basin in America, the artesian basin of Queensland is the largest yet discovered in the world. It is nearly as large as the American basin, and in its proved thickness of water-bearing rocks and their storage capacity, and therefore economic value, far exceeds it.

To quote the late Government Geologist, Dr. Jack:

"A central sea existed in Mesozoic times, and was then filled up to a large extent by sediment in Cretaceous times. These were subsequently—in Tertiary times—uplifted, and formed, with the Palæozoic rocks, a united continent. Further depression again submerged part of the coastal and central land, and these depressions were followed by a re-elevation. The climate during these periods of depression was doubtless much more moist and equable than at present. Before the deposition of the Cretaceous sediments there were mountain chains on the eastern side of Australia, almost Alpine in character, with which

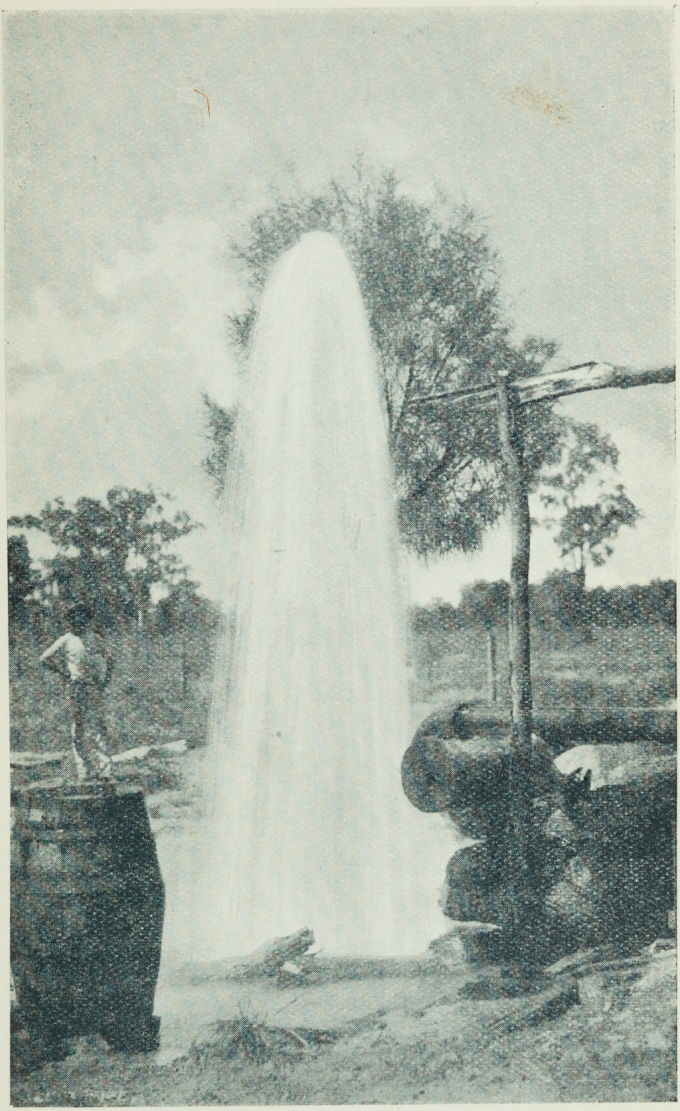


Charlotte Plains Bore, Queensland. Depth, 1,920 feet; flow, 3,500,000 gallons per diem; temperature, 120 degrees Fah.

(Kerry & Co., Photo.)

the ranges of the present time are insignificant in comparison. These mountain chains induced great precipitation of the water held in suspension in the clouds by which they were, in all probability, constantly surrounded. Before the beginning of the Cretaceous period—of the deposit of the Cretaceous formation of thousands of feet in thickness, consisting of alluvial strata, including the artesian-water-bearing rocks—the whole continent had subsided, but the strata lying above the Cretaceous—which has been proved in Queensland to be over 5,000 feet in thickness—shows the great length of time which must have elapsed in the formation of the present surface, the great tablelands, or rolling downs, of the interior. Taking into consideration that during the Tertiary age there was a great deposit of rich alluvial soil from the decomposed material of the ranges, and also considering the climatic conditions prevailing, it is easy to imagine that the vegetation was of a most abundant and luxurious character, especially in the vicinity of the lakes, swamps, and inland rivers. Those conditions resulted in the development of a great variety of animal life, notably of an herbivorous fauna of gigantic proportions, the fossil remains of which have been found in the Post-Pliocene strata of the Darling Downs of Queensland and in the interior of South Australia. Those remains marked, no doubt, the course of ancient rivers, or the position of ancient lakes."

The changes in the physical conditions of the country, as pointed out by Dr. Jack, which brought about the gradual extinction of the huge fauna, can, I believe, be accounted for by natural forces. As the high



Beel's Bore, Queensland. Depth, 1,706 feet; flow, 5,500,000 gallons per diem; temperature, 109 degrees Fah.

(Kerry & Co., Photo.)

mountain ranges became lowered, and the precipitation of torrential rain became thus reduced, when the river and lake sources of moisture had been destroyed, the climate underwent a gradual change. A condition of excessive moisture was followed by one of partial aridity; the long, succulent, luxuriant vegetation gave way to a shorter and less prolific, although more nutritious, growth, till finally aridity ruled, and brought about the droughts of the present day.

The greater part of the western interior of Queensland, or nearly 400,000 square miles, is composed of soft strata of Lower Cretaceous age, consisting of clay shales, limestones, and sandstones. These strata are so disposed that the lower members of the series crop out on the western flanks of the coast range, where the elevation of the surface is greater than in the downs to the west, and the rainfall is comparatively abundant. All along the eastern margin of the Cretaceous area there is a great thickness of an exceedingly porous sandstone, so incoherent that when saturated with water a piece of it will crumble instantly into sand. This rock, called the "Braystone," is an ideally permeable stratum; and owing to the low dip its outcrop occupies a belt varying from 5 to 70 miles in width, but it finally disappears beneath the argillaceous and calcareous upper members of the series which form the soil of the downs to the west. The outcrop of the "Braystone" is not visible for the whole of the distance from north to south, as it is partly concealed by nearly horizontal tablelands of what is called "Desert Sandstone." This stone is an upper division of the Cretaceous formation, and lies unconformably on the

Noorooma Bore, Queensland. Depth, 1,502 feet; flow, 2,304,000 gallons per diem; temperature, 110 degrees Fah.

(Kerry & Co., Photo.)

lower. Where it directly overlies the permeable Lower Cretaceous strata, it does not, however, seriously interfere with the absorption of water by the latter, being itself of a fairly permeable nature.

The first sub-artesian water obtained by boring in Queensland was by Government in 1882. This was under my superintendence, at the 14-mile dam near Cunnamulla. The first artesian water obtained was at Back Creek, 20 miles from Barcaldine, on the Central Railway, but the supply did not amount to much. The bore was sunk at a very low spot, and in all probability did not tap the same sources as that obtained subsequently further west. The first artesian bore started in Queensland was that at Blackall (Government) in January, 1886, but it was abandoned, waterless, at a depth of about 1,000 feet, the cable system used in drilling it proving unsuitable. The Barcaldine Government Bore can fairly claim to have given the first important artesian supply tapped in Queensland. The tools to sink it with were landed from Canada in July, 1887. The machinery was made principally in Sydney. The bore was commenced on the 18th October, 1887, and water was struck on the 28th November following. It is needless to say the work was watched with the keenest anxiety, and when, after six weeks' work, water was struck at a depth of 691 feet, there was great rejoicing. When the Barcaldine water baptised the Western Plains, it was felt that a new lease of life had been secured, and that drought had been robbed of some of its terrors. The flow of water at Barcaldine is still 175,000 gallons per diem. After the success of this bore the plant was moved further along

Yarmouth Bore, Queensland. Wool-Scouring Plant.

(Kerry & Co., Photo.)

the railway extension, and water was struck at a depth of 978 feet. While the Barcaldine Bore was being put down, a plant was moved to Blackall, and the bore there deepened to 1,663 feet. This bore was completed shortly after the railway bore—known as the 21-mile—had struck water, and a fine flow of 300,000 gallons per diem was obtained The plant was then moved to Tambo, where water was obtained at a depth of 1,002 feet. A bore was then put down at Winton to 1,125 feet. The next bore was made by the Aramac Divisional Board, on the Aramac-Barcaldine Road, in February, 1890. Work was being carried out at this time on Saltern Creek Station. The first bore struck water at a depth of 570 feet, but was carried down to 1,130 feet, when a supply of 175,000 gallons per diem was secured. This bore was the first to settle the then vexed question as to whether or not a second, and greater, volume of water existed below the proved first supply. The answer being in the affirmative, boring operations were then pushed vigorously and earnestly ahead. Two more bores were successfully sunk on the same station, yielding 4,350,000 gallons of water daily. Previous to this a second bore had been made at Barcaldine, and, this also proving successful, the fact of artesian water existing all along the Western Downs, within a certain distance of the edge of the "desert," was established. Early in 1891 water was struck, at a depth of 2,700 feet, on Darr River Downs, and, being carried to a further depth of 3,630 feet, a large supply—500,000 gallons—of water was struck. By this time water had also been struck on Warenda Station, near Boulia, and this fully establishes the

Yarmouth Bore, Queensland. Wool-Scouring.

(Kerry & Co., Photo.)

fact that artesian water was to be got all over the Western Downs, depth being the only consideration. Boring was then pushed into the north-west country, and was most successful on the Flinders, at Richmond Downs, Cambridge Downs, Marathon, Saxby Downs, and other stations. Good results were also obtained at Landsborough Downs, Barenga, and Afton Downs, and also at Katundra. Probably the most successful stations, when result and cost are taken together, were Coreena, Aramac, and Stainburn, the two last being—to quote the words of a well-borer—"able to run creeks on their stations at pleasure." While work was so satisfactorily progressing in the central and north-west districts, many bores were under way in the south-west, and here amazing results were obtained. At Burandilla two startling overflows were secured, one of 4,000,000 and the other of 2,500,000 gallons daily. No. 2 bore on Charlotte Plains yielded, at a depth of 1,848 feet, 4,000,000 gallons; Coreena Bores, Nos. 2 and 5, yielded respectively 1,500,000 and 1,000,000 gallons of fine water per diem; while on Tinnenburra (Tyson's) seven bores threw out 8,000,000 gallons of fine water daily; and Boatman No. 1 bore discharges 4,200,000 gallons in the same time. And so the work has gone on, until it is officially stated that there are at the present time 596 flowing bores, of a total daily outflow of 390,846,909 gallons, 60 of which flows are over 1,500,000 gallons per diem, ranging as high as, at Cunnamulla, 4,500,000, and, at Coongoola, 6,000,000 gallons (officially measured) per diem—a phenomenal output.

The total number of wells, public and private, is 973—an increase of 13 during the year. The total

Richmond Downs Bore, Queensland. Cattle watering.

(Kerry & Co., Photo.)

aggregate depth bored to the end of June, 1904, was 1,188,211 feet, equal to about 225.04 miles. The average depth of the bores east and west of the Dividing Range is 1,221 feet. The aggregate flow of all Queensland bores would represent 62,635,722 cubic feet, or 1,438 acre-feet daily. The estimated value of the 973 bores is approximately £1,485,264. The deepest bore is at Bimerah. It is 5,046 feet. The flow is 70,000 gallons daily. The shallowest bore is on Manfred Downs. Its depth is 10 feet, and its flow 2,000 gallons daily. (See "Mound Springs," page 20.)

There are no records available of the channelling which has been made on the various stations and from the Government bores for the purpose of watering stock, but its total length must be very great, some of the stations having led the water as much as 40 miles to a boundary fence.

The Government Statistician gives in his last Report, under "Irrigation" the following particulars:— In eight districts the sources of supply were wholly or in part artesian. The aggregate irrigation by bore water was 3,952 acres, or 27 per cent. of the total area irrigated. In two districts large acreages were thus provided—viz., Cunnamulla, 2,760 acres, and Barcaldine, 855 acres. Wheat, oats, maize, vegetables, as well as lucerne and artificial grasses, are the principal crops cultivated.

Richmond Downs Bore, Queensland. Cattle watering.

(Kerry & Co., Photo.)

VICTORIA.

The Victorians have, with their usual well-known enterprise, been assiduous in testing their State for artesian supplies, with more or less success. One of the first artesian wells made in Australia was that put down at Sale, in Gippsland (private), in 1880. The depth of the well was 234 feet only. The flow rose 16 feet above the surface, and the supply was 36,000 gallons per diem.

Boring has been largely, and is still being, carried on in Victoria in search of water in the Post-Tertiary and Tertiary deposits, which occupy about one-half of the area of the State. Artesian water has been struck at Mordialloc, the flow amounting to 65,000 gallons per diem. Fresh water has been struck in many of the bores, but the supplies are much less than those tapped in other parts of Australia.

In 1897 Dr. R. L. Jack, then Government Geologist of Queensland, wrote as follows on the "Extension of the Underground Waters under the Mallee Scrub": "On the invitation of the Minister for Mines and Water Supply of Victoria, I joined Mr. James Stirling, Government Geologist, and Mr. E. Checci, Government Engineer, in an investigation of the chances of the Queensland artesian water being found under the agricultural area of the Mallee Scrub. The conclusion arrived at was that, after flowing subterraneously southwards into New South Wales, the Queensland water was prevented from reaching the Mallee country by a bar of Palæozoic rocks, and its possible outlet to the ocean was narrowed down to that part of the southern coast-line between the 124th and 134th meridians of east longitude."

The Report is highly instructive, as the question is approached not only from the geological standpoint, but also from that of the hydraulician. It is unfavourable so far as the Mallee country is concerned. There is one point, however, which is but slightly touched upon, and that is the question of leakage of the artesian waters into the sea through the outlet mentioned on the South Australian coast. This is a part of the subject which is, I think, open to further investigation.

The strata passed through in the successful undertakings are, as stated, of the Post-Tertiary and Tertiary ages, and no equivalents to the water-bearing formations of the other States have, so far as I can learn, been so far met with. The Victorian Government have expended since 1886 large sums of money in the search for artesian water.

SOUTH AUSTRALIA AND THE NORTHERN TERRITORY.

A geological examination by the Government Geologist, Mr. Henry Y. L. Brown, shows that a very large area of the State is a wide Cretaceous basin, extending from the Queensland and New South Wales borders to the outcrop of bed rock near Farina, the limits on the west, so far as now known, being a bore at Lake Phillipson, Goyder's Lagoon Bore, 70 miles south of the Queensland border near Birdsville, and a bore at Charlotte Waters, just over the border in the Northern Territory. The Cretaceous water-bearing rocks fill a depression, of which Lake Eyre is the lowest surface area, lying, as it does, a little below sea level. The Lake Eyre district was originally a basin, which is now filled in with more or less horizontal beds of shale, with sandstone, limestone, etc. The greatest thickness of the deposit, as proved by boring, is some 1,300 feet. This is the chief artesian-water-bearing formation, and into it several borings have been made, yielding large supplies of good water. Mound springs—*i.e.*, natural artesian wells—are numerous in some parts of this area, and discharge enormous quantities of water in a continuous flow. Of these the Dalhousie Springs are the most extensive, occupying altogether an area of about 10 square miles. Overlying the Cretaceous rocks are horizontal beds of argillaceous sandstones, kaolin, and gypseous clay, usually capped by jasper-rock or quartzite, forming table-topped hills and lands.

A considerable area—about 110,000 square miles—in the north-east corner of the State is occupied by

a portion of the great Australian artesian basin. A considerable number of borings, from 300 to 4,850 feet in depth, have resulted in flowing wells, and the water from most of the bores is of excellent quality. Some of the most successful bores are as follows:—

	Depth in feet.	Gallons per diem.	Temp. deg. Fah.
Coonamia	2,030	500,000	134
Goyder's Lagoon	4,850	600,000	208
Mount Gason	4,420	480,000	204
Mirra Mitta	3,534	470,000	190
Mungeranie	3,370	600,000	187
Kopperamanna	3,000	800,000	176
Dulkaninna	2,226	1,000,000	148
Lake Crossing	1,703	130,000	115
Yandama	1,642	432,000	132
Coonamia	2,030	500,000	134
No. 2 Muloowurtina	1,432	314,000	128
Anacoora	1,250	700,000	135
Oodnadatta	1,571	270,000	—
Storm Creek	1,550	86,000	115
Hamilton Creek	1,417	232,000	115

The main artesian basin is represented by the same formations as those already described in the artesian areas of New South Wales and Queensland—viz. Desert Sandstone (Upper Cretaceous), Rolling Downs formation (Lower Cretaceous), and Triassic beds. The last mentioned are typically developed at Leigh's Creek, to the south of Lake Eyre, where Triassic fossils and coal seams occur, the former similar to those of the Ipswich Coal Measures of Queensland and the Clarence beds of New South Wales.

The Northern Territory has an exceptionally large extent of well-watered country. The Roper River, which empties into the Gulf of Carpentaria, is *permanently* navigable for vessels of large tonnage for

over 100 miles. The yearly rainfall increases with every mile, from the boundary of South Australia, where it is about 5 inches, to 70 and 80 inches on the north coast, as at Port Darwin. The successful artesian bore at Charlotte Waters, just over the border, the furthest yet made north, promises well for artesian supplies and sub-artesian water, and water similar to that found in large quantities in the cavernous limestone formations in the interior of Western Australia, may be reasonably expected to exist.

WESTERN AUSTRALIA.

Western Australia was, until comparatively recently, as little known as the Northern Territory of South Australia is at the present time, but the great magnet, gold, not only attracted a great access of population, but the search for it has been indirectly the cause of an extended exploration and knowledge of the other physical resources of the State.

Although it has been found that flowing artesian water is not available over a great part of the goldfields areas — the geological formation not being favourable — other parts of the State are liberally endowed with artesian supplies. In the last Report (1904) of Mr. A. G. Maitland, Government Geologist, is the following:—

"In its broader topographical features Western Australia falls naturally into three divisions of different physical character:

(1) **The Coastal Plain.**—This consists in reality of a fringe of strata round the coast, with a more or

less gentle slope seaward, of shallow-water deposits, for the most part sandstones, conglomerates, and thin shales, with occasionally incoherent sand and clays. It has a width of 60 to 70 miles in places on the western coast, though in the country at the head of the Great Australian Bight, which is absolutely devoid of rivers, it extends some 200 miles into the interior. Its inner margin reaches an altitude of 600 feet above sea level in certain localities. The coastal plain is separated from the interior by a belt of—

(2) **Hill Ranges**, which form what may be called the escarpment of the plateaux and plains of the interior. The hill ranges have an average elevation of about 1,200 feet, though isolated ranges reach altitudes of 4,000 feet above sea level. This escarpment has a short, or steep, slope down to the edge of the coastal plain, into which it gradually merges. This belt of country, drained by the rivers of the State, is formed of granitic and metamorphic rocks, the decay of which produces excellent soil. It comprises, owing to its rainfall, the principal agricultural districts of the State.

(3) **The Plateaux and Plains** of the interior consist of a broken tableland, from which rise isolated hills and ridges of metamorphic rocks, often separated by sand plains of some considerable extent, and containing depressions occupied by saline marshes, clay flats, brine lakes, or deposits of salt. There are no rivers, and the rainfall is slight. This plateau forms the chief mineral region of the State.

The coastal plain is of considerable economic importance, in that the certainty of obtaining artesian

water from the underlying strata has been very thoroughly established, and the system of boring for artesian water is capable of great expansion in the State, being limited only by locality.

A glance at the geological map of Western Australia shows an enormous extent of Recent and Tertiary strata entering the State at its eastern border, in the Nullarbor Plains, and extending without any interruption as far as Israelite Bay. These strata consist of porous limestones, associated with beds of water-bearing grits, into which the rainfall is rapidly absorbed and discharged seawards in the form of freshwater springs. Where these strata have been pierced on the South Australian side of the border, the section invariably shows from 300 feet to 500 feet of sandy water-bearing beds of undetermined age, covered by a variable thickness of calcareous strata of both Older and Newer Tertiary age. The beds have a prevailing dip towards the Great Australian Bight, and water rises in the bore-holes to sea level. So far, however, the water obtained has proved to be either salt or brackish, but, at any rate, suitable for stock purposes.

The whole area of these beds in the southern portion of the State is an artesian-water area; though there undoubtedly are conditions affecting the water supply such as local variations in the thickness, the relative porosity of the beds, and the unevenness of the floor upon which they were laid down, which, with our present meagre knowledge, can only be set at rest by the operations of the drill.

The strata of the coastal plain in the vicinity of

the Swan River have proved that in certain areas they possess all the conditions necessary for yielding an overflowing supply of water. The structure of the coastal plain differs in some respects from the typical areas in which artesian water has been obtained in eastern Australia. The strata are horizontal, or nearly so, though occasionally there is a slight local dip of about five degrees in places. The effect of this horizontality is shown in the fact that the water-carrying beds do not crop out on the surface at the foot of the Darling Range, but impinge directly against that portion which is now concealed from view. These beds (clays and sandstones, with occasional limestones) do not maintain a uniform thickness throughout, but are lenticular, and some appear to have exceptionally absorptive properties.

The bores which have already been put down between the Darling Range and the coast have shown how irregular are the strata from which water is obtained, and, what is of further moment, they also demonstrate that only in one instance has the base of the water-carrying beds been reached.

The first supply of artesian water in the vicinity of Perth was obtained some time during the year 1873. Since then all the available information about artesian wells has been collected and tabulated. So far as official data show, there are now 44 artesian and sub-artesian wells in the State, of which some particulars of flow, depth, etc., are given in the following table:—

TABLE OF BORES—ARTESIAN AND SUB-ARTESIAN.

	Total Depth of Bore in feet.	Depth to Principal Water-Bearing Bed below surface in feet.	Artesian. Continuous Daily Flow in gallons when uncontrolled.	Sub-Artesian Volume Pumped or Available Daily in gallons.
Wyndham, Town of	690	...	...	...
Onslow, Town of ...	1,729	1,015	...	...
Carnarvon	3,011	...	515,000	...
Geraldton	420	...	...	...
Geraldton	1,531	1,531	...	11,700
Dongarra	2,111	1,478	216,000	...
Yardarino	1,607	1,607	589,000	...
Midland Junction ..	500	420	266,000	...
Woodbridge ...	236	160	124,000	...
Guildford	408	408	60,000	...
Guildford	798	784	192,000	...
Woodbridge ...	691	691	200,000	...
Guildford	1,202	1,140	1,167,000	...
Guildford	340	304	71,000	...
Guildford	404	199	65,000	...
Bayswater	1,100	1,070	536,000	...
East Perth	948	948	217,000	...
Leederville	1,113	1,023	217,000	...
Perth	820	820	384,000	...
Subiaco	876	876	...	450,000
South Perth ..	1,856	1,837	454,600	...
Causeway, East Perth	1,200	...	825,000	...
East Perth	1,034	...	171,700	...
Melville Park ...	1,487	1,487	54,000	...
Cannington... ...	1,000	...	99,000	...
Fremantle	456	434	...	565,200
Railway Station, Bunbury	30	...	...	...
Estuary, Bunbury ..	104	97	...	70,000

	Total Depth of Bore in feet.	Depth to Principal Water-Bearing Bed below surface in feet.	Artesian. Continuous Daily Flow in gallons when uncontrolled.	Sub-Artesian Volume Pumped or Available Daily in gallons.
Stirling Street, Bunbury	426	86	100,000	...
Dardanup	453	...	...	...
Dardanup	1,032	...	...	...
Fremantle	1,322	433	...	1,070,000
Claremont Reserve..	1,506	1,189	...	...
Eyre No. 2 ...	430	410	...	15,000
Eyre No. 1 ..	2,101	2,080	...	...
Leederville	1,680	1,375	...	...
Perth	815	600	...	...
Woodbridge ...	242	236	...	...
Claremont	1,500	1,320	...	...
Near Carnarvon ...	100	...	...	...
Midland Junction ..	322	280	...	...
Midland Junction ...	875	600	...	...

A remarkable feature of the above discharges is the great yield of the sub-artesian bores, especially that at the Port of Fremantle of 1,070,000 gallons pumped per diem.

It is from the strata of the coastal plain that the supply of artesian water has been hitherto obtained. This area consists, as stated, of a narrow coastal plain extending between the western flanks of the Darling Range and the Indian Ocean. Its width at Perth is about 20 miles, widening somewhat in a northerly direction. The greatest altitude of the intake beds, where they dip off the flanks of the Darling Range,

must be some distance to the north of Perth, probably near the source of the Swan River, for the level of the artesian water at the Guildford Bore is at a greater altitude than the eastern edge of the coastal plain where it meets the Darling Range near Guildford. The rock underlying the surface of this coastal plain is a coarse and very porous æolian sandstone, containing fragments of marine shells of existing species. Its disintegration has resulted in the formation of a surface covering of sand. A feature of special interest in this artesian basin is the apparent fact that there is an absence of any continuous impervious rock covering above the artesian-water-bearing beds. This suggests the inference that an impervious stratum is not an absolutely essential part of an artesian system.

The Collie Coalfield is a small isolated artesian area at the southern end of the Darling Range. The water occurs in coal measures of Mesozoic age. The coal is being worked near the outcrop of the seams. The basin rests on a floor of granite, and the greatest altitude of the Mesozoic rock is towards the north, the dip being in a southerly direction.

Rainfall.—The average rainfall of the coastal plain, in the vicinity of the Swan and the Canning Rivers, is over 30 inches per annum, a precipitation which is fairly considerable. The rainfall is disposed of in three ways—evaporation, surface "run off," percolation. It is the balance that is left after evaporation and "run off" which is available for absorption by the strata upon which the water falls, and is capable of being reached by wells. The data collected and tabulated by the Public Works Department with

reference to the actual discharge of the Helena River shows that a good deal of water must disappear underground. From the figures recorded it can be shown that, on an average, about *twenty-two thousand million gallons* annually falling on the catchment area does not reach the gauging weirs; in other words, allowing nothing for evaporation, there is a total possible absorption of a little short of twenty-two thousand million gallons of water per annum. There does not appear to have been, as yet, any noticeable diminution in the supply from the bores in the metropolitan area. A lessening, or even the cessation, of the flow would not of necessity indicate permanent exhaustion, for there is always a come-and-go, as it were, in the level of underground water. A diminished flow, due either to lateral leakage, through superincumbent porous beds, or the choking of the bore due to "creep," which may affect such soft and plastic rocks as clays and clay shales, or such loose rocks as sand and half-coherent sandstone; the accumulation of sand and fine mud, or some mineral product; and the wearing-out of or defects in the piping, can be remedied by methods known to engineers. In the event of any constant draft upon the underground supply having any serious effect, there should be a distinct and marked diminution of the pressure, which constant observation alone can detect. So far as any of the official observations have at present been carried, it does not appear that any considerable diminution in static head has resulted. Obviously, if the annual draft exceeds that which the water-bearing beds can absorb and transmit (for a good deal depends upon the rate at which the water can reach

the well), a time will come when, after the water accumulated during long periods has been excessively drawn upon, the flow of water over the surface will diminish, or possibly cease altogether. A decrease in the flow, due to the exhaustion of the head by a constant daily draft, is irremediable. The possibility of such can be minimised by shutting off the water at such times as the water is not required. The records of the bores at present put down demonstrate that, with the possible exception of that of the Melville Park Estate, none have been carried deep enough to reach the crystalline rocks forming the floor upon which the strata of the coastal plain rest. From all the available evidence, it seems highly probable that there are other water-bearing horizons (perhaps of greater water-carrying capacity) than those at present known to exist under the metropolitan area.

In order to test the artesian possibilities of the deeper ground, it would, on purely geological grounds, be advisable to put down wells at relatively wide distances apart, in order that a much larger area of water-bearing strata could be drawn upon. The distribution of the wells is a matter of considerable importance. In the event of experimental boring being undertaken, it would seem desirable to carry out the operations, subject to local modifications, along a line at right angles to the direction of the flow of underground water; or, in other words, to the intake area—*i.e.*, the boundary between the strata of the coastal plain and the crystalline rocks.

The consideration of the question as to whether the rich pastoral lands lying between the Gascoyne and the Ashburton Rivers are capable of yielding artesian

water is very much a matter of geological mapping. According to the information extant, it appears that the Lyndon River practically drains the Carboniferous, Mesozoic, and Tertiary formations. These formations contain beds of such a nature as to readily absorb a large portion of the water which falls upon them, and the various members are so disposed that the lowest of the series crops out on the higher ground which forms the watershed of the Minilya, the Lyndon, and the Henry Rivers. So far as these indications go, there is a probability of artesian supplies."

I have quoted this fully from Mr. Maitland's report because I agree substantially with what he says. The geological evidence may, of course, be accepted with full confidence, but the hydraulic views promulgated seem less decided. In further consideration of the subject, it will be seen that artesian water supply is one both for the hydraulician and the geologist, to the exclusion of neither one nor the other. The movement, pressure, and other conditions of water involve special and very intricate study.

Extent of Boring Operations.—The latest official statistics give 19 artesian wells in the metropolitan area reaching an aggregate depth of 17,738 feet. Total flow, 5,669,504 gallons per diem, or 2,069,368,960 gallons per annum. The deepest well is that in the Zoological Gardens, Perth, depth 1,856 feet, the flow of which is 372,384 gallons per diem. The largest flow is that of the Guildford municipal bore, which equals 1,120,000 gallons per diem. Few observations seem to have been made as to temperature, but to the present time that of Melville Park Estate bore, on the Canning River, is the warmest—viz., 91° Fah.

Although the most recent explorations of the interior of Western Australia—those due to mining operations in particular—show that artesian flowing water is not available, a great store of underground water has been found to exist. Nearly all the numberless mining shafts have had to contend with water, often in formidable quantities, which, although strongly saline, has by condensation, in the absence of rainfall, proved the saving of the industry in its initial stages, which, without it, could not have been carried on. When engaged under the Water Supply Department, and in reporting upon the gold-fields' water supply for the "Mining Journal," Perth (before the advent of Sir John Forrest's great Perth-Coolgardie water-supply scheme), the condensation of the shaft waters was a revelation to me; the wonder was that the simple apparatus of the miners (subsequently largely superseded by great Government condensing installations) had not been adopted in the Western pastoral townships and camps of other parts of Australia. Had it been, there can be no question that much disease and sickness would have been avoided by the residents. The pioneer Western Australian gold miners pressed every conceivable article into the service, which consisted simply of an iron tank, as boiler—or anything made of iron—seated on earthwork, and a fire lit under it. Iron piping, sometimes made of bent galvanised sheets, seated on wooden trestles, the piping long enough to allow the steam to condense and the water to cool off and run as *absolutely pure* water into receivers of any and all descriptions.

Very large quantities of good water are also procurable in the limestone formations of the interior.

Says Mr. Gillet*:—"After entering upon the limestone formation, the country, which had hitherto consisted largely of open forest, opened out into grassy and saltbush plains, which extended to Eucla. There we discovered many caves or holes, which appeared to penetrate to a great depth into the earth. We examined two of these caves. On approaching the edge of these natural wells, we were astonished to hear, proceeding from a vast depth, a noise as it were of a mighty torrent—a dull, sullen, continuous roar. Pieces of rock thrown into the abyss returned no sound, beyond the rebounding from side to side, until ultimately lost to hearing, but no splash could be heard; yet still the ever-varying roar of water continued, tantalising enough to those who, whilst they heard the sound of rushing water, had still no means of obtaining it."

Previous to the advent of the gold industry, the districts had been well watered, as is proved by the fact that little had been done in water conservation, the settlers depending almost entirely upon springs, streams, and shallow wells. In the northern or pastoral districts there are large pools in, and bordering on, the river beds, which are, as a rule, annually flooded; or water can be obtained by either scratching in the sand of the beds or by shallow sinking in the flooded plains. The stations are almost entirely worked by native labour, and one native can with ease water his flock (of about 1,000) with a bucket and rope. Many of these shallow water supplies have been opened up in the Murchison district, where

* Proc. Roy. Geog. Soc. of Australasia, Vol. x., No. 3.

station-holders have fenced their runs so that the sheep can walk to the water themselves.

This all, I think, tends to show that the popular impression that Western Australia and the Northern Territory are hopeless drought-ridden interiors is an erroneous one.

OCEAN OUTLET AND DISCHARGE.

This has been somewhat of a vexed question in scientific circles in Australia; and, as it has an important bearing, both upon the quality and the quantity of the water at disposal, I will endeavour to throw more light upon it.

Mr. J. P. Thompson, Government Surveyor, late President of the Royal Geographical Society of Queensland,* has contended that Australia is formed with the eastern part high, and that it dips towards the centre more rapidly than the western half, which gradually and imperceptibly slopes inwards; that most of the inland basin is flat, the soil and upper stratum highly absorbent, while the lower portion of its bed in several places is not much, if indeed at all, above sea level. For this reason, and in view of the general physical structure of the continent as a whole, the theory of subterranean channels—through which it is believed that large volumes of rain water find their way to the sea — he holds to be altogether erroneous. Leakages, he says, occur along some parts

* Trans. Roy. Geog. Soc. Queensland, Vol. xi.

of the coast-line, oozing through the porous strata, or in form of bubbling springs, such as may be met with along the shores of most of the Pacific islands; but the necessary evidence to sustain the theory that large volumes of fresh water are discharged into the ocean through subterranean channels is not at present available. On higher levels, where the waters pass over, or are collected in, highly absorbent Cretaceous beds, some are retained, from which the artesian supplies are probably derived; but even here a very large percentage is lost by evaporation, which he thinks sufficient to account for the speedy drying-up of the shallow water-holes and river-beds.

Here we have the admission, to begin with, that rainfall does discharge itself through water-bearing rocks into the ocean, places being mentioned where this takes place along various coast-lines.

In the absence of actual knowledge of the depth at which much of the artesian formation lies with regard to the ocean level, we can only be guided by the proved great depth of other portions of it below that level. I think, therefore, there is every reason to believe that the bulk of the enormous body of water that enters the water-bearing rocks empties itself sooner or later at the lowest level attainable, which is at points far down in the declivity, or even the bed of the ocean.

This seems more obvious when it is taken into consideration that surface rivers running from the intake areas to the ocean do not exist; showing that the rain is absorbed by the water-bearing rocks, which, by discharging themselves into the ocean allow subsequent absorption of further rainfall. The opinion

that a very large percentage of the rainfall is lost by evaporation, which, it is said, "is of itself sufficient to account for the speedy drying-up of shallow water-holes and river beds," is, I think, altogether erroneous.

I have watched the action of creek water at flood time in various parts of Queensland, especially in the Cretaceous country, and have repeatedly seen the flood water come down a " banker " at one point in a creek, while at ten miles, or less, below that point it was, within a few hours' time, easy to ford in a foot of water. I have also made a number of practical experiments in absorption and evaporation from the surface after floods in various parts of Australia, and have invariably found that, when once the rain water has entered the parched and highly absorbent ground, the bulk of it is safe, although evaporation goes on quicker at first from the saturated surface than it does from water itself. So soon as the sun asserts itself, the surface, as a rule, becomes in a short time—a few hours at most—caked or hardened, and this hardening acts as a covering, or anti-evaporative, to the water below. I am quite convinced that evaporation to the extent the imagination of some thinkers suggests to them is non-existent, and that this source of loss does not seriously affect the subterranean supply. When once the bulk of the water has sunk into the porous, highly-absorbent ground, it is safe. In stretches of country which in flood times form creeks, lagoons, or swamps, a great part of the flood water passes into the highly-absorbent ground long before water accumulates visibly on the surface, leaving a small portion only—the

surface water—liable to evaporation. The water passes down, by its own gravity, through an inconceivable number of minute interstices, until it meets the resistance of a watertight bed, on which it either lies or travels to still lower levels.

Most important evidence of the great depth of the Cretaceous formation is afforded by the temperature of the water flowing from the bores, which is generally taken to be due to the internal heat of the earth, which increases at the rate of 1 deg. Fah. for every 55 feet in depth. Among the many theories advanced to account for the high temperature of artesian water are the following:—

1. Contact with rocks of igneous formation that have retained sufficient heat to regulate that of the water passing through them.
2. Contact with strata that generate heat by the application of water.
3. The dip of the water-bearing rocks to great depths between the outcrop and the bore site.

The highest temperatures of which I have information are those of Goyder's Lagoon Bore, South Australia—208 deg. Fah., nearly boiling point (212 deg.), and at Dagworth Bore, Queensland—197 deg. Fah. Taking the mean temperature of the air at the surface at 60 deg. Fah., and an increase in every 55 feet of 1 deg. Fah., we have $208° - 60° = 148 \times 55 = 8{,}140$ feet, as the depth at which the water in the Goyder's Lagoon Bore would derive its temperature of 208 deg. If this theory be a sound one—and it seems to me the most feasible—it affords confidence in making bores to even greater depths than those yet carried out. Taking another case, that of the Toorak Bore, Flin-

ders River, where the surface levels in the vicinity are known, and give about 600 feet above sea-level, the temperature of the water is 140 degrees. The bore is 1,600 feet in depth; the bottom of it is, therefore, 1,000 feet below sea-level, and, according to the above mode of calculation, would be about 3,000 feet below that level. Looking at the configuration of the coast, it is, as I have said, within reasonable belief that the enormous layers of water-bearing rocks have a termination and outlet in the declivity of the coast far below the ocean level.

Various localities have been assigned for these ocean outlets—viz., the Gulf of Carpentaria, the Great Australian Bight (viâ Lake Eyre), and under the present channel of the Darling-Murray to the Coorong coast. The measurements of the flow of water past a given point (Bourke) in the Darling River, made by the late Government Astronomer, Mr. H. C. Russell, show that a small portion only (1.46 $^{o}/_{o}$) of the catchment water is discharged by the river Darling, the bulk of it sinking into the ground. Taking these observations, which extended over 10 years, and results as a guide, it is easy to conceive a similar passage for the Queensland catchment-area water. The bores now in operation in that State cannot account for the passage of the enormous volume of water that passes into the outcrop of the water-bearing formations. Without giving particulars of all the abundant evidences of the discharge of fresh water into the sea on the Australian coast, one may, however, be mentioned in particular—much noted by South Australians—that in the neighbourhood of Streaky Bay, between Port Adelaide and Eucla, where an enormous

volume of fresh water is seen to rush out at low tide from beneath the cliffs, preserving its freshness for some distance out to sea. This underground flow and escape of fresh water in the sea elsewhere in large quantities is mentioned in "Humboldt's Travels." In the Gulf of Mexico there is a submarine outflow a considerable distance from the South American coast, which converts so large a space into a fresh-water lake that it is inhabited by the fresh-water crustacea found in the Orinoco River. There is also an abundant flow of fresh water in the Indian Ocean, 125 miles from Chittagong and 100 miles from the coast of the Sunderbunds.

My own opinion upon this question—expressed repeatedly in this country during a long course of years and study—is that the artesian-water-bearing formations absorb an enormous quantity of water; that the evaporation of the rainfall at their source of supply is, comparatively speaking, not worth consideration; that they consist of a series of basin-shaped undulations, and that they exist, in all probability, mostly in continuous connected layers from the outcrop, or highest, or intake, levels of the formation; and that the surplus water finally oozes out slowly but continuously by gravitation into the bed of the ocean. Did those outlets not exist, the water-bearing rocks, being fully charged, would admit no more water, and the result would be inevitably a system of surface rivers which do not now exist, and a flooded state of the country at the intake areas, and particularly below, to an extent of which one can scarcely conceive.

The following extracts from papers read subsequently by Dr. R. L. Jack in 1902,* and jointly by Mr. E. F. Pittman and Professor David in 1903,† will be found to confirm the views I held in Queensland upon the question. Dr. Jack says:—"But the loss of the rivers which flow across the outcrop of the Braystone is itself sufficient to suggest a serious consideration. The water must, to some extent, escape, or the Braystone could not continue to absorb it, and the rivers would continue to run over the clay soil of the western downs. It follows that these *must* have some outlet; and there are strong grounds for believing that the underground water finds an outlet in the Great Australian Bight. The sea-bed is not open to observation, but if the water escapes where we suppose it does, the Blythesdale Braystone must, after dipping and undulating beneath the soil of the interior, crop out somewhere to the south of Australia. This conjecture, as will be shortly seen, is supported by observations on the water-pressures of the artesian wells themselves. It is now almost equally certain that a portion of the water escapes into the Gulf of Carpentaria.

The idea that water entering the porous beds ultimately finds its way to the sea by underground channels, or by percolation through the intervening portions of the earth's crust, has been for a long time a matter of vague speculation on the part of theorists, who did not take into account, or who were ignorant of, the essential

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* Proc. Victoria Inst., London, Jan., 1902.

† Proc. Roy. Soc. of N. S. Wales, Vol. xxxvii., page 103.

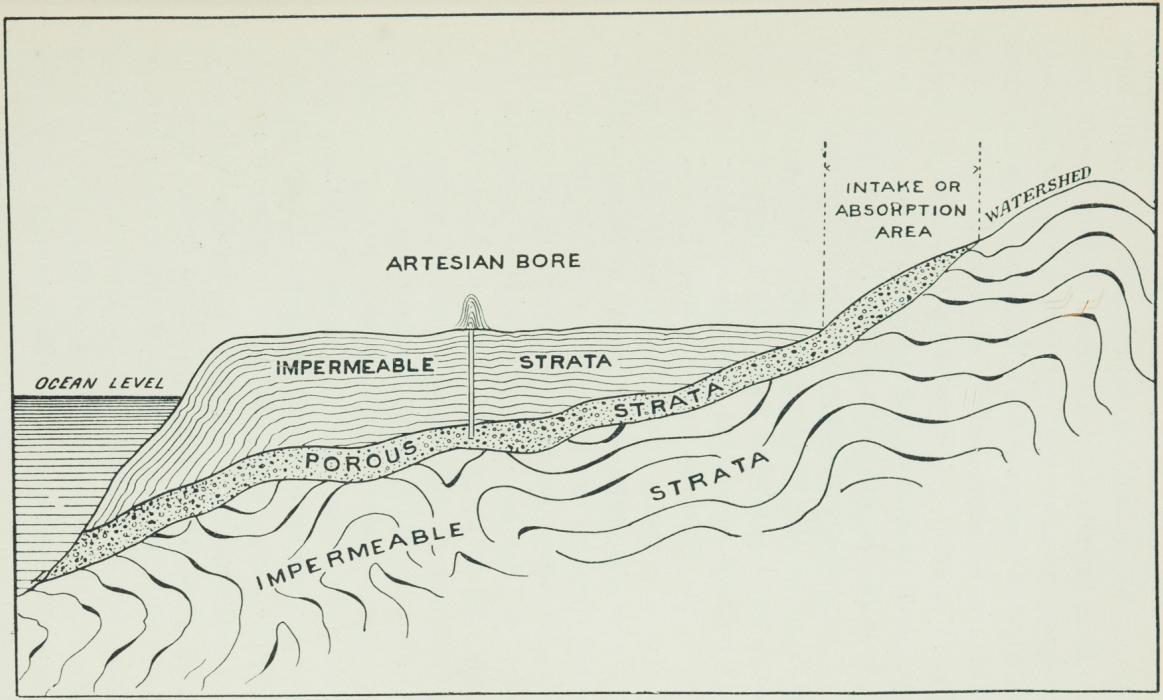

Fig. 1.—Section of the Artesian Formation: From its outcrop on elevated country to its outlet in the bed of the ocean. (Not drawn to scale.)

element of the geological structure of the region in question. That such a communication could only take place through the medium of the intake beds themselves, may be said to have been the common knowledge of geologists for a long time; but, so far as I am aware, as regards the Australian area, that was distinctly pointed out in 1893 by Professor T. W. E. David, who discussed the probability of the continuity of the porous beds of the Lower Cretaceous formation to the Gulf of Carpentaria in the north and Lake Eyre, or the Coorong Coast, in the south. In Bulletin No. 1 this idea was further dealt with, and it was insisted upon that the loss of water by such rivers as the Darling, and presumably the Queensland rivers, crossing the outcrop of the Blythesdale Braystones, amounted to a proof of the circulation of water through the Braystone itself to the sea, inasmuch as the comparatively trifling amount discharged by the bores now in existence would not make a void in the porous strata anything like sufficient to absorb the annual loss of water by the rivers, and no other outlet than the sea was conceivable. The conclusion was drawn that the water-bearing strata must run into the sea, and that, unless the strata were periodically replenished, the sea level would ultimately become the level to which the water of the bores would rise. A drought sufficiently long to bring about this result would, no doubt, have for a prior result the destruction of the greater part of the land fauna of this part of Australia, including the 'Genus Homo.' Far short of this, however, we can conceive the temporary diminution, or cessation, of the flow of some at least of our artesian wells. The

amount of water contributed to the water-bearing strata of the Lower Cretaceous every wet season by such rivers as the Darling is so great, and consequently the amount of leakage into the sea is so great, that the quantity abstracted by the artesian wells, large as it is—and even if it were ten times greater—is insignificant in comparison."

Mr. E. F. Pittman and Professor David, in their joint paper, say:—"These facts point to the conclusion that the rise of the water in the artesian bores of the western plains must be due to either hydrostatic or hydraulic pressure. We believe the pressure to be hydraulic (moving) rather than hydrostatic (stagnant), for the following reasons: (1) If the pressure were hydrostatic—that is, if there were no outlet for the water which accumulates in the porous beds—it stands to reason that it would ultimately become saturated with the mineral matter dissolved from the rocks through which it had percolated. As a matter of fact, however, the water in the artesian wells contains only a small amount of mineral matter in solution, and this fact must be regarded as evidence that the water has a circulation. There are valleys in the artesian area which could intersect the porous beds at a sufficient depth to allow of this circulation; and the amount of water which escapes from the mound springs within this area is so small that it may be regarded as negligible. The only other possible way in which circulation could be maintained would be by leakage to the ocean. That there is leakage to the ocean is borne out by the fact that the porous beds have been found to extend along the eastern and south-eastern shore of the Gulf of Carpentaria.

It may further be stated that if there were no circulation of water in the artesian beds—that is, if the water were hydrostatic instead of hydraulic—it appears to us that the beds must long ago have become saturated with water, with the result that numerous strong springs would be observable in the valleys intersecting the intake beds. No such springs, however, are known to exist.''

In studying the question of the condition of the artesian underground supplies, it may be permitted to advance a view as regards their quality in the possible, if not probable, future, and to draw a deduction therefrom. It is easy to conceive that, if the whole of the water-bearing rocks were emptied before the next flood season, the flood water would, after the rocks had become again surcharged, issue from the bores in a perfectly fresh condition, entirely free from alkaline elements. It follows, therefore, that the more the bores are multiplied, and the greater the resultant outflow, the purer the water should become. The few exceptional cases where analysis has shown bore water to be heavily charged with deleterious mineral matter have doubtless been due to an excess locally of such elements, but it is evident that, if the draught by outflow were increased, such waters would be rendered less stagnant, and the quality would improve accordingly.

These considerations lead to the conclusion that every effort should be made by the States' Water-Supply Departments to have the whole subject of artesian supplies submitted to scientific research, in order that in every artesian area we may know the limit to which bores may be safely multiplied without reducing the hydraulic grade—or, in other words,

interfering with the outflow. This phase of the subject will be considered more fully under the head of "Hydraulic Considerations of the Artesian Supply," page 87. (See also map at end of volume.)

POTENTIAL ARTESIAN RESOURCES.

In the paper already mentioned, Messrs. Pittman and David say:—

"The area of the intake beds has not yet been accurately surveyed, but it may be provisionally stated to be approximately 18,000 square miles. As the mean annual rainfall on this area is 25 inches, it follows that 1,045,000,000 cubic feet of water falls upon it annually. If it be assumed that only 20 per cent. of this rainfall is absorbed by the intake beds (and we consider this is a low estimate), a volume of water equal to 3,580,273,972 gallons per diem would percolate through the porous beds under the western plains. This volume is more than 27½ times the amount which at present flows from the 284 bores which have been put down.*

The Storage Capacity of the Porous Beds.—The area of country underlain by water-bearing beds in New South Wales is approximately 83,000 square miles. The thickness of the beds intersected in the bores varies from 600 feet in the east, near the intake, to 100-200 feet on the western side of the area. There are therefore about 471 cubic miles of water-bearing sandstone in the artesian area of New South Wales,

* There are now 296 bores flowing night and day in New South Wales.

and, assuming that this sandstone will absorb 12 per cent. of water, these 471 cubic miles of porous stone will hold 56½ cubic miles of water. As the six principal tributaries of the Darling have eroded their channels through the intake beds, there must be a great leakage of their water into the porous beds of the artesian area, and this is no doubt the reason why such important rivers as the Macquarie never reach the Darling except in flood time. Hence the estimate already given of the quantity of water absorbed by the intake beds from rain falling upon them must be increased considerably by reason of the water flowing down these rivers from areas to the east of the intake beds. As, however, this increase is an unknown quantity, it has been omitted from the calculation, and we would accordingly emphasise the fact that our estimate of the amount of water annually absorbed is probably a minimum one.

With reference to our statement that the water annually absorbed by the intake beds exceeds by 27½ times the amount which is being drawn from the existing bores, it must not be inferred that it would be possible to increase the flow from bores to that extent.

If our view as to the pressure being hydraulic be correct, it is obvious that there must be a point beyond which the bores could not be multiplied without so lowering the hydraulic grade, by diminishing the frictional resistance to the movement of the water, as to convert artesian into sub-artesian wells."

As an hydraulic engineer, I am of opinion that 20 per cent. is a very low estimate for the absorption of the rainfall. How is the intake to be increased?

There is a way of greatly increasing it, although, under existing conditions of land tenure and financial ways and means, it may not be feasible. The following mode, which has suggested itself to me, of adding to the inflow has not, that I am aware of, appeared in any scientific, Governmental, Press, or other writings upon the subject:—

The present surface of the intake areas consists mostly of close, although more or less porous, surface soil, with plant growth. A portion only consists of bare rock. Water falling upon this bare rock is absorbed at once, passes down by gravity, and is thus conserved from evaporation. A great portion of the water falling upon the surface soil is absorbed by that soil, and is partly taken up by evaporation as from a layer of sponge. If a portion only of the outcrop areas, in a line with and near the upper edge of the outcrop, were cleared of all surface accumulations down to the face of the absorptive rock—as is the case with the rivers and creeks crossing the line of outcrop, whose flood waters have scoured down to the rock surface, and are lost therein—a much greater intake would be obtained. The rock would then also absorb even moderate rains, which are now partly lost by evaporation from surface soil, as well as completely intercept the flood rainfalls. Under present conditions, intake action is confined to flood waters only, and those *not to the fullest extent possible.* Instead of the calculation of the quantity of water absorbed by the outcropping rocks being limited to 27½ times the amount now flowing, 40 times would be a nearer proportion in future calculations.

An increased water supply to the interior of this country is of such vital importance that it seems to me that expenditure in the direction I indicate may eventually be undertaken. Enormous quantities of water are periodically available through rainfall over the artesian outcrop areas, but, under existing conditions, they only, as I point out, partly enter the artesian system. If the intakes were rendered more effective and regular, the bores and outflows on the surface could be greatly increased, and brought up to their *fullest possible* capacity.

As regards the absorptive capacity of the artesian rocks—and this is a very important point—12 per cent. appears to me to be, likewise, a very low estimate. The chalk formation of the London artesian basin gives an absorption of 3 gallons per cubic foot (the cubic foot containing 6¼ gallons), which is nearly 50 per cent., and certainly samples of the rock I have brought up from bores near the outcrop in Australia, and weighed when fully saturated and when thoroughly dry, have given very nearly that percentage. The heavy sand-pump used in the pole system frequently brings up a core which, upon being exposed to the air, falls apart at once into a mass of wet sand. It would surely require more than 12 per cent., or even 25 per cent., of water to produce such a result. I think, therefore, that 30 per cent. would be a nearer estimate.

In studying the artesian rocks of the adjoining States of New South Wales and Queensland, alone of the Australian States, which may be taken to be representative ones, we come upon some astounding figures. The Government Reports show that the area

of country already proved to be underlain by artesian water-bearing beds in New South Wales is, approximately 83,000 square miles, and in Queensland 376,000 square miles, making a total of 459,000 square miles. The thickness of the beds varies from 600 feet to 100-200 feet. There are therefore about 2,133 cubic miles of water-bearing sandstone in the artesian areas, and assuming, as I do, that this soft, highly-porous stone will absorb 30 per cent. of water, these 2,133 cubic miles of strata will hold 640 cubic miles of water. The areas of the outcropping porous rocks—the intake areas—amount approximately in New South Wales to 18,000 square miles, and in Queensland to 50,000 square miles, making a total of 68,000 square miles. The mean annual rainfall on this area is about 25 inches; it follows that 3,971,000,000 cubic feet of water fall on it annually. If it be a fair assumption, as I think it is, that 30 per cent. of this rainfall is absorbed by the intake beds, a volume of water equal to 7,445,625,000 gallons per diem percolates through the porous beds under the western plains.

Possibilities of Irrigation for Fodder Crops.—Although a great portion of the water now flowing is used for stock consumption, being led over the runs, the utilisation of the water for the purposes of irrigation is only in the initial stage—although a few station-holders have been very successful in their enterprise in this direction. There is an immense quantity of water now running to waste which could, and should, be used for irrigating land for raising fodder for stock in times of drought, as the following short statement will show.

		Gallons per diem
The present outflow in New South Wales and Queensland ...		546.000,000
Allow for seepage and evaporation 20 per cent.	109,200,000	
Water consumed per diem by sheep on artesian areas, say 35,000,000 sheep at 2 gallons per head	70,000,000	179,200,000
Surplus		366,800,000

One inch of rainfall gives 22,622 gallons per acre; 20 inches per annum (allowing four waterings of 5 inches each) gives 452,440 gallons per acre; and 366,800,000 gallons per diem would irrigate 295,911 acres with 20 inches of bore water per annum, or would irrigate at the rate of nearly 330 acres at each of the 895 bores treated upon. A bore giving 1,000,000 gallons per diem, plus natural rainfall, will irrigate, at the rate of 1 cubic foot per second, 500 acres, costing 7s. 6d. per acre per annum, made up as follows:—

	£	s.	d.	£	s.	d.
Cost of bore at average depth of 1,280 feet, at 25s. per ft.	1,600	0	0			
Cost of irrigation	500	0	0			
	£2,100	0	0			
Interest at 6 per cent. per annum...				126	0	0
Interest on cost of irrigation plant				10	0	0
Maintenance wages				52	0	0
				£188	0	0

VARIATION IN THE AMOUNT OF FLOW FROM ARTESIAN BORES.

A variation in the pressure and flow of some of the wells has been observed. It is possible that there may be some connection between the variation and periods of heavy and light rainfall on the intake beds, but until accurate measurements of a large number of bores have been made over a series of years, speculation on the subject is hazardous. In Lancashire and Cheshire, England, the effects of dry and wet seasons do not show themselves in the deep artesian wells of the new red sandstone till about six months after their occurrence, this period being required for percolation. It is impossible at present to state how long it would take the artesian waters of Australia to travel hundreds of miles along their beds from the intake areas; but the last prolonged drought doubtless had effect in varying the flow.

In addition to the long-period variations in the flow from artesian wells (says the paper already referred to of Mr. E. F. Pittman and Professor David), the artesian water has been observed at one locality—Urisino Station, Wanaaring to Milparinka Road—to be subject to some very remarkable oscillations. At this station there is a well 30 feet deep, from the bottom of which a bore has been put down to a total depth from the surface of 1,680 feet. The water rises in the well to a mean height of about 17 feet below the surface. The temperature of the water has been recorded as 120 deg. Fah.

The oscillations of the water, as shown by a tidal gauge for a period from 28th February to 18th May,

1897, were as follows:—The variation in time between successive ebbs and flows was from about 9 to 14 hours, while the rise and fall of the water varied from about 3 feet 3 inches to 3 feet 9 inches. Different results were obtained by observations taken during two short periods—viz., from November 6th to November 12th, 1894, and from May 30th to June 3rd, 1896. In the first-named period the successive ebbs and flows occurred at intervals of about 17½ hours, whereas in the latter the interval was about 10 hours.

This occurrence at Urisino raises the question as to whether a similar phenomenon may not obtain at all the artesian bores, and this could be ascertained by attaching pressure gauges to the outlets, and observing whether the pressure varies from time to time.

Observations have recently been made by the University at Capetown, South Africa, and have been embodied in a paper on artesian wells in South Africa, read before the recent meeting at Capetown of the British Association for the Advancement of Science. The opinion put forward is that the rise and fall is clearly due to lunar influence—that the artesian water is subject to the same law as is that of the ocean.

Although the lowering of the hydraulic, or water, grade may appear to be a serious matter, it is not so in reality, because the recorded oscillations, both in Africa and Australia, do not influence the discharge to any appreciable extent.

A reduced flow may be also accounted for by inferior casing; leakage at the joints; deterioration of metal; or by a portion of the water finding its way up outside the casing into dry upper strata; or from temporary choking of the well at the bottom, due to re-

duced pressure, which is the effect of prolonged drought.

CONDITIONS GOVERNING THE RISE OF THE ARTESIAN WATERS.

Fig. 2 illustrates the conditions governing the rise of the artesian waters.

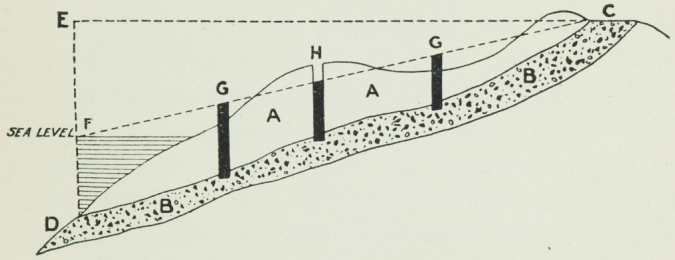

Fig. 2.—Conditions governing the rise of the Artesian Waters.

The line E C shows the hydrostatic surface—*i.e.*, the height to which water would rise in a bore in a perfect artesian basin with no outlet; F C, the hydraulic surface—a line drawn from the intake to the sea, being the line to which water should rise in a bore between the two points, on the theory of an outlet to the sea, giving artesian water where the surface of the land is below the hydraulic surface, and sub-artesian where the land surface is above the hydraulic surface. The piezometric height is represented by a vertical line dropped from the hydraulic surface through the site of the bore to the water-bearing stratum. The piezometric height is above the surface where there is artesian water, and below the surface where there is only sub-artesian.

Actual measurements of pressure in the flowing bores—from which, of course, the height to which water would rise in a pipe can be calculated—show that the hydraulic surface of fact corresponds so closely with the hydraulic surface on the theory of a submarine outlet, that the theory seems practically justified.

Iso-Potential Map.—A map has been prepared on the American system by the Hydraulic Engineer of Queensland, Mr. Henderson, on what are called Iso-potential lines, or lines along which the pressure would raise water to equal heights above the sea. The value of the iso-potentials cannot be over-estimated; for, where the observations are sufficiently numerous to allow them to be drawn with accuracy, they enable an intending borer to judge beforehand, provided he knows the level of the ground, whether he can hope to strike a flowing supply or whether his expenditure will be thrown away.

Another useful map has been compiled by the Geological Department (Queensland), called an "equi-altitudinal" map, in which, by treating the various bores as so many soundings, a fair idea may be given of the contour of the upper surface of the water-bearing beds at the base of the Cretaceous formation. From this map it appears that these beds come near the surface, or even reach the surface, on a saddle extending east and west from the Woolgar to the Cloncurry (Queensland), in a manner which is suggestive of a delta thrown across one of the narrowest parts of the sea which, in Cretaceous times, divided Australia into two islands. By referring all the bores to the sea-level, and making contour lines join-

ing those in which the beds are the same height above or depth below the sea, the fact is brought out that the water-bearing beds form two basins or scoops, one deepening northward to the Gulf of Carpentaria, and the other deepening from Hughenden to the south-west, or towards Lake Eyre and the Great Australian Bight. This, to my mind, amounts to a demonstration of the seaward flow of the underground artesian water.

HYDRAULIC CONSIDERATIONS OF THE ARTESIAN SUPPLY.

Without going into abstruse scientific calculations of the hydraulic problem, which have been most ably carried out by Mr. G. H. Knibbs,* the salient points of the subjects may be given as follows:—

The main question is whether the outflow is in excess of the periodical increase from flood waters at the intake areas. The whole question centres upon this. As regards surface flows and bore pressures, it is known that the water-bearing stratum varies in thickness, and that the thicker the stratum the greater is the pressure, and vice versa. We also know that when the pressure in any bore is greater than that of a head of water equal in height to the depth of the bore, the bore will flow; but the flow may be impeded by the condition of the bore through corrosion, incrustation, or escape of water outside the casing into dry superincumbent strata. The rate of

* Proc. Roy. Soc. N. S. Wales, Vol. xxxvii, page 103.

flow and pressure will depend upon the nature of the water-bearing stratum, its thickness, size of particles and porosity—all unknown factors.

In order to reduce the question to as scientific a basis as possible, it will undoubtedly be necessary to examine it in a thoroughly scientific manner. As the question presents mathematical difficulties of a very special character, it should be placed in the hands of a mathematical hydraulician, with full powers to make all necessary tests at all bores, and flow and pressure observations at all new bores, and complete records of strata gone through should be insisted upon at all bores.

It is much to be regretted that these scientific observations were not insisted upon at the initiation of boring operations. Observations of varying pressure and flow should have been made at the beginning of the operations, and continued to the present time. "In rightly deciding," says Mr. Knibbs, "the most probable initial pressures and other conditions of the artesian stratum lies the true solution of the problem." In the meantime, whatever further scientific systematic measurements and mathematical investigations may establish, it may be permissible to indulge in a prophetic mood, and by inductive reasoning endeavour to arrive at an approximation to the truth.

Under the heading "Sub-Artesian Water Supply," I allude, in connection with locating bore sites, to "a borer of long experience utilising his knowledge, and the *intuition* which has become by a slow, but sure, process natural to him." Such intuition may equally be applied in taking a broad and comprehensive view of the natural elements of the question before us.

We know that the source of the water is rainfall of a certain average liberal amount; that it falls over great areas of outcropping water-bearing rocks, and that additional quantities of the rainfall are supplied by rivers crossing the outcrop areas. We also know, approximately, the absorptive capacity and the great thickness of the rocks, and that they underlie an enormous extent of country. We do not, however, know the extent and—in a purely hydraulic sense—the velocity, of the flow at the presumed outlet in the bed of the ocean. I have already stated that, in my opinion, the flow is a slow one. When we consider the nature of the water-bearing sandstone; that although it is porous, the interstices, or water-passages, in it are microscopically minute and extremely crooked, it seems reasonable to infer that the passage of water, even under considerable pressure, must necessarily be slow. If it were otherwise, the soft sandstone would not hold together. The resistant pressure of the sea water at the point of discharge is also a factor to be considered, and undoubtedly—although to an unknown extent—impedes the flow at the outlet. We know, further, that enormous quantities of water have been running regularly for years from hundreds of bores without cessation or diminution of flow, even after the last phenomenally long drought. We know, too, that artesian supplies have failed or become sub-artesian in other countries, because of an excess in the number of wells and outflow over small areas with dense settlement (as in the London artesian basin); but this is not likely to happen in Australia for a long time to come. Given the evidence already obtainable regarding this question,

and after many years of careful study over a great part of Australia, an intuitive feeling will, I submit, assert itself, that the present artesian water supply of this country is not at all likely to fail, nor would it do so were the bores multiplied *thirty or forty fold.* The three main elements, viz., the enormous areas of water-bearing rock; the great intake areas; the liberal rainfall entering those intakes—which, great as it now is, may be much increased—and the presumably slow ocean discharge, all intuitively point to a very large underground conservation. In addition, an increased flow would, in all probability, as I have pointed out, produce a greater purity of the water, and therefore an elimination of all risks in using it.

ARTESIAN BORES AS AFFECTING CLIMATE.

The question has been propounded as to whether the action of the water from numerous bores in the interior of the country would induce moisture sufficient to coalesce with the rainy atmosphere of the coast and thus bring about rainfall in that interior. This question has often occurred to me in my practice, which has been in the driest parts of the interior of this country.

In all lake districts, with their accumulation of inland surface water, the rainfall is greater than in the adjacent country. This I found to be the case during a visit I made a few years ago to the chain of reservoirs which supply one of the largest cities in Great Britain (Manchester) with water. With a heavy periodical rainfall, it was found that, during spells of dry weather in the adjacent country, rain

fell invariably, more or less, over the line of the reservoirs. I remarked the same effect in sections of the United States of America, where irrigation from bored wells, in the closely-settled farms, induced a more regular, although light, rainfall than that which took place on the unsettled prairie lands of the country.

If the large additional supply of artesian water, which it may be reasonably anticipated will in the future be brought onto the surface of Australia, does not actually induce rainfall, it will certainly render the atmosphere more moist, and, therefore, further conducive to plant growth.

MACHINERY.

The first borings for artesian water were made, there is every reason to believe, by the Chinese. They were made by the aid of a "trepan," or weight of iron, provided with a set of cutting chisels at the bottom, suspended by a rope, and worked with a lever by hand power. This method was so slow and laborious that it is recorded the bores took the lifetime of the workers, and in some cases were bequeathed, as a legacy, to their successors, who accomplished them, as might be expected from the well-known plodding industry and persistence of the Mongolian.

The earliest European people who turned their attention to artesian-water supply, some four centuries ago, were the French. They used, at that time, very primitive apparatus, which was much improved upon in their more recent undertakings—the great wells of Paris, the success of which brought

artesian water into note and use, especially in the Western farming States of America.

Two of the most important wells bored in France are those of Grenelle, completed in 1842, and Passy, in 1861. A description of these works, showing the time expended in carrying them out, the cost, and the kind of machinery used, shows the very great advance made in the last 45 years in the art of well-boring, which has been mainly due to the great development of the petroleum and farming industries in the United States of America.

The Grenelle well is remarkable as showing the skill and patience exercised in overcoming the risks and difficulties incidental to well-boring in its earlier stages. The well was commenced in 1832, and took ten years of continuous work before flowing water was struck. This was at a depth of 1,780 feet. At 1,259 feet over 200 feet of the rods accidentally broke loose and fell to the bottom of the bore, and it took fifteen months of experimenting with extracting tools and other devices before they were recovered. This so discouraged the Government that abandonment of the bore was proposed, but, in deference to forcibly-expressed scientific advice, it was continued until, at the depth stated, a flow of nearly 900,000 gallons per diem was obtained, from a bore of about eight inches in diameter.

The bored well at Passy is 1,913 feet in depth, 28 inches in diameter, and discharges an uninterrupted supply of 5,500,000 gallons per diem. The tool used was a "trepan" for breaking the rock, consisting of two principal pieces—the frame and arms, both of wrought iron, the framing having at the bottom a

series of holes into which cutting chisels were inserted and tightly wedged. These chisels were placed with their cutting-edges on the longitudinal axis of the frame, at the extremity of which were formed two heads, forged out of the same piece as the body of the tool, which also carried two teeth placed in the same direction, but double their width, in order to render this part of the tool more powerful. As iron rods, from their jarring, and thus fracturing the metal, and on account of their great weight, would have rendered them unmanageable, and as a great part of the boring was made in water from the upper springs, stout rods of oak, eight inches square, were used. The sliding-joint of Eyenhausen—the present "jar" of the English, Americans, and Australians—was also adopted, by means of which the re-acting force of the blows of the trepan were absorbed. After a bore 3 feet 4 inches in diameter had been made to a depth of over 1,700 feet, the upper part of the boring caved in and filled up the hole. On operations being resumed, the bore was contracted to a diameter of 2 feet 4 inches, and, at a depth of 1,904 feet, a supply of perfectly good water was struck, which quickly increased to 5,500,000 gallons per diem; and it has been running, without any diminution whatever, ever since. This enormous supply reached a height of nearly 60 feet above the surface. The boring was commenced in 1855, and completed, as stated, in 1861. The cost was nearly £40,000.

The next method employed in France was the Dru system, the most important wells bored by it being those at Butte-aux-Cailles, to a depth of 2,900 feet, with a diameter of 47 inches; and at the Sugar Re-

finery at Paris, to a depth of 1,570 feet, with a diameter of 19 inches. The apparatus employed consisted of a drilling-rod and chisel, suspended from the outer end of a working beam, or lever, made of timber, working upon a middle bearing for a fulcrum, and connected at the other end to a vertical cylinder, of 10 in. diameter and 39 in. stroke. The steam cylinder was single-acting, being used only to lift the boring-rod with the trepan at each stroke, the rod being lowered again by releasing the steam from the top side of the piston. In the construction of the trepan the points aimed at were simplicity of construction and repairs, greatest force of blow possible for each unit of striking surface, and freedom from liability to get turned aside and choked. This machine was the forerunner of the English "Mather and Platt" system. The distinctive peculiarities of this latter method consist in the means adopted for giving the percussive and rotary actions to the boring tools, and also in the construction of the tool or boring-head, and of the sand-pump for clearing out the hole after the action of the boring-head. A full description of this machine would show that, although it is a powerful apparatus, and entitled to admiration for the ingenuity displayed in the arrangement of its parts, it is not adapted for the conditions of work peculiar to the interior of this country. Not only the complication of its parts, but the great comparative weight of the whole plant, and its excessive cost, precludes its use in the inland districts of Australia. Our present simple "American"—an equally powerful and effective apparatus for deep drilling, with its record already achieved in Australia for some of

the deepest drilling in the world—is the fittest for this country, where lightness, simplicity, and power combined are the ruling desiderata.

Diamond Drill.—In one of the Government Reports is the following*:—"The boring plant in general use for sinking artesian wells does not fulfil the conditions of a perfectly scientific apparatus, because it does not produce a core, by means of which the nature of the strata can be fully ascertained." In the early modern stages of artesian water development, the diamond drill which produces a core was brought into requisition, and is now being employed in the exceptionally hard strata common to auriferous areas, as in Western Australia—in the search for artesian water. It has had a full and fair trial in the alluvial—Cretaceous—country, but without sufficient success to secure its adoption.

The difference between the hardness of some of the rocks and the best of steel cutting tools is, in drilling, in favour of the former. This gave rise to the adoption of the hardest-known substance, the diamond, to perform the work of boring through them. Fortunately this substance existed in another form besides that of the gem, the costliness of which would have precluded its use in boring operations. The imperfectly crystallised form known as carbonate, which until the advent of the drill had little commercial value, has been admirably suited for the purpose. It is by abrasion alone that the diamond drill works, and not by percussion, as in the steel-cutting tools of the American pole and cable system It is capable of piercing the hardest rocks—even

* Queensland Water Supply Dept., 1893.

emery has been bored at the rate of two inches per minute—but in soft strata, such as clay, sand boulders, and other loose alluvial deposits of the artesian formation, it is open to very serious objections, in some cases proving worse than useless. The form of the diamond-studded cutter-head is not adapted to work its way through the alluvial strata freely, especially through loose boulders and compact shale and clay.

The Calyx Drill.—This drill is similar in principle to the diamond drill, but it is much lighter, less complicated, and consequently easier to transport. In the calyx drill, steel cutters are used instead of diamonds, which are more liable to fracture or loss.

The elements which have secured to this drill considerable success lie in (1) the shape of the cutter; (2) the calyx or cup; (3) the means of gripping the cores which it cuts; (4) the mechanism for chipping the rock, insteading of grinding it; (5) this drill can be worked by hand or horse power, or by gas or steam engines.

The calyx drill will penetrate water-bearing strata and the milder Silurian. It has been used largely in Victoria and Western Australia, and to some extent in New South Wales, in boring to over 2,000 feet, in which cores have been obtained; but it is questionable whether either the diamond or the calyx drill can compete in the open market—say, for station work—with the pole and cable system. That system has drilled through the hardest rocks in artesian work, although in such strata—which is less frequent than in auriferous country—it works slowly; but, at any rate, it reaches water, the quickest and best progress being made (sometimes as much as 100 feet per diem)

in loose and soft strata, in which the diamond drill is at its worst. If the deepest drilling in Australia, and one of the deepest in the world, through every kind of strata, hard and soft, of 5,045 feet, at Bimerah, Queensland, could have been possible with the diamond drill or the calyx, the cost would have been so great that nothing but an extreme exigence of science would have justified it.

In early times—I am writing of the year 1877—shaft-sinking was the common mode in all the States of obtaining underground water, 100 feet being considered a deep well. This was somewhat natural in the alluvial "diggings" of the time. Boring by hand-power had scarcely made a beginning. The shaft was, however, gradually superseded when the borer's drill showed better work, and when it was found that more water could be raised by cheap pumping power from the bores—which were lined with wrought-iron watertight casing — than could be hauled up by bucket, and that the sinking was much faster, cheaper, and safer than by means of slabbed shafts. There was a strong "opposition" at the time by the regular shaft-sinkers, and even the station hands and the selectors severely criticised the novel operations. "A six-inch hole was so insignificant compared with a noble-sized shaft," and "the bore would hold no water," and "the operation of boring itself was, in a physical sense, almost beneath notice"—were a few of the sentiments promulgated.

In later years a good deal of heavy machinery for deep drilling was brought into operation; but, now that further experience has been gained, and the probable depth to water is easier to estimate, lighter apparatus is being used.

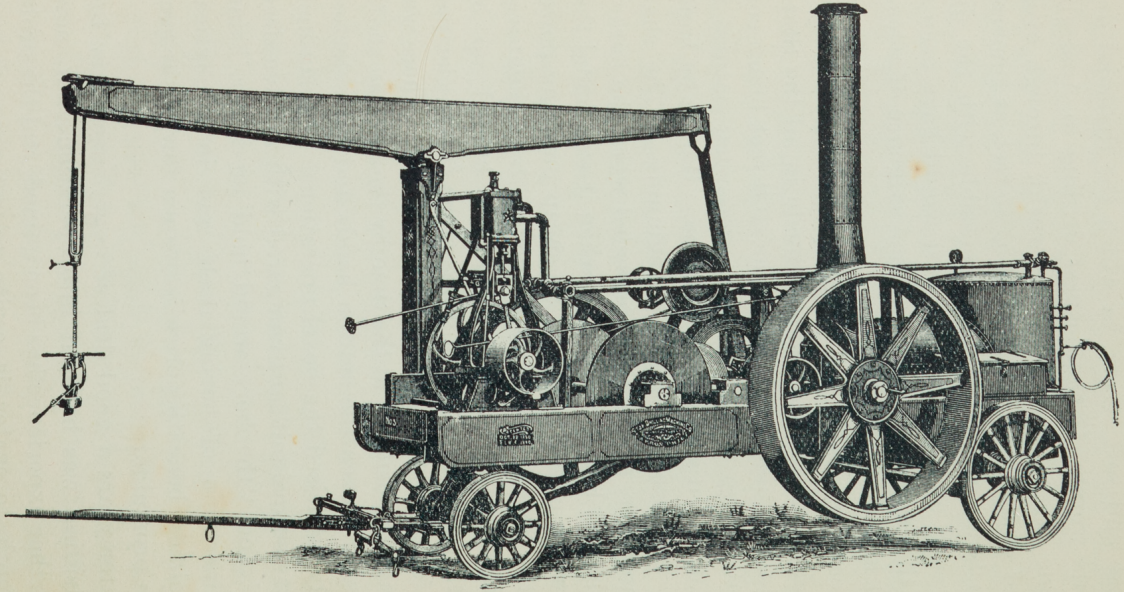

Fig. 3.—2,000-ft. Drilling Machine, with Spudding and Pipe-Driving Attachment.

The Most Modern Plant.—The following is a description of the most modern machinery (see Fig. 3). It is a portable rig, the engine and drilling apparatus being combined on one platform. It is capable of drilling to a depth of 2,000 feet; and, as the average depth of the bores in New South Wales and Queensland is about 1,300 feet, this simple and compact class of machinery is all that will generally be required.

LIST OF TOOLS.

One rope socket, 2½ ft.
One set of steel jars, 5½ ft.
One auger stem, 3¾ in. by 25 ft.
Two 5⅝-in. bits, 80 lbs. steel each.
Two 8-in. bits, 100 lbs. steel each.
All standard taper joints.
One temper screw.
One 10-ft. bailer for 8-in hole.
One 16-ft. bailer for 5⅝-in. hole.
Two tool wrenches.
Wrench circle.
Wrench bar.
Wrench hook.
One 8-in. drive head.
Pair heavy drive clamps.
Chain tongs.
40-in. bellows, or blower, on machine, as desired.
130-lb. anvil.
Sledge hammer.
Drive belt.
Draw belt.
Bit gauge, 5⅝-in.
Bit gauge, 8-in.
Extension tongs.
15-in. monkey wrench.
Hand axe.
Hand saw.
Brace and bit.
File.
Cold chisel.
Oil can.
Oiler.
Flue cleaner.
Shovel.
Funnel for filling boiler.
Engine wrench.
Belt punch.
Belt lacing.
Belt clamps.
Stoving post.
Wood handle for turning tools.
Wood handle for putting on bits.

Weight of machine and tools about 12,500 lbs.

Boiler Fittings—Steam gauge, pop valve, gauge cocks, glass water gauge, injector, strainer, and hose.

Engine Fittings—Light feed lubricator and engine wrench.

Derrick.—Single pole derrick, 44 ft. high, 10 by 10 in. This derrick is spliced in centre, and also has derrick brace, 4 by 8 in., 33 ft. long, running from near top of derrick to frame of machine at crank wheel box. Has a 34-in. spudding pulley, and 10-in. sand-line pulley. Derrick is guyed with five galvanised wire guys, fastened to iron stakes in the ground, and tightened with turn buckles.

The following are dimensions of parts of the machine:—

Sides: 5½ in. thick, 15 in. wide, 18 ft. long. The cross pieces of the frame of machine are of the same width and thickness as the sides. Width of frame, 5½ ft. outside.

Walking Beam: 8 in. thick, 17½ in. wide at centre, tapering to ends; 18½ ft. long.

Sampson Post: 12 by 12 in. at base, 9 by 11 in. at top, 6 ft. high from frame of machine.

Waggon Wheels: Felloes and tyres 5 in. wide, rear hubs 13 in. in diameter, 15 in. long, with 5 by 14 in. skeins; front hubs 12 in. in diameter, 14 in. long, with 4½ x 13 in. skeins.

Upright Engine: 8-in. bore, 8-in. stroke; balance-wheel 38 in. in diameter, having an extra heavy rim; driving pulley, 13-in. face, 18 in. in diameter, for 13-in. belt. Engine has reverse link.

T Boiler: 42 in. in diameter, 64 in. high, waist 30 in. in diameter, 3 ft. 10 in. long; 24 3-in. flues; 60,000 lb. T.S. steel, tested to 150 lbs. pressure; ash-pan, with

bottom, fire and ash-pan door; solid ring in door, grates, and boiler stack.

Band Wheel: 78 in. in diameter, 12-in. face crowning, with 13-in. 4-ply belt.

Bull Wheel: Iron centre and wood rim; 45 in. in diameter, for 7-in. draw belt. Has belt tightener and brake band lever.

Bull Wheel Flanges: 32 in. in diameter, wrought iron, with cast-iron supports.

Sand Reel Flanges: Cast iron, 24 in. in diameter. The plant also has the following—Waggon pole, double-tree, whiffletree, and neck yoke.

Each contractor exercises his own particular views upon the details of construction and working; but the main principle of the system is that of a balanced beam resting upon a middle bearing, to one end of which the cable or poles, with the chisel attached, are suspended, the other end being given an upward and downward movement by means of a crank movement worked by a steam engine. Any foundry, such as those at Adelaide, Sydney, Brisbane, and Rockhampton, will show diversity in details in the make of boring plants, dependent upon the mechanical idiosyncrasies of contractors, and there is no subject in which warmer discussions ensue among them than on the particular make, size, and working of rival machines, although they are all based upon the established principle I describe.

The present machinery for deep-drilling is, I think, all but perfect. Like the steam-engine, it may be open to improvement in minor details, which extended practice may call for, but I cannot conceive that, for the general purposes of its special work in

the interior of this country, it is likely to be superseded by any other mode. It has a unique history, and in its embodiment of some of the best mechanical thought, exceptionally thorough and extended practical experience, and persistent energy of a long succession of practitioners, it stands, I believe, as near perfection, for its purpose, as human efforts can make a machine.

The geological features, however scientifically they may have been approached, were, in the early stages of the movement for an artesian-water supply, little understood, and it was not until the artesian engineers commenced work that real advance was made. Professional geologists will, I am sure, freely admit that they have been, and will still be, largely dependent upon the exposition of strata, given by actual borings, for the most reliable data upon which to frame their reports, and to finally perfect their maps. Moreover, the best and most economical means must be adopted to give the water vent to the surface.

In Great Britain the scientific papers read on the artesian-water supply of the wells of the London Basin and other parts of England were almost invariably confined to the headquarters of engineering —the Institute of Civil Engineers, London. They were submitted to very keen criticism and discussion. and will be found invariably to include a dissertation on the necessary machinery, as well as the geological and hydrological features of the subject. In the United States of America—one of the most advanced scientific countries in the world—the greatest possible attention is given to the mechanical and the practical features of any subject under treatment, however much of other science may be involved in it.

The following account of one of the deepest borings in the world, if not the deepest, shows the class of machinery used in that highly-experienced community, Pittsburg, Pennsylvania, U.S.A. When a comparison is made between the heaviest machinery used in Australia—that at Bimerah, Queensland, of 5,045 feet in depth—and that at Pittsburg, it seems apparent that it was not so much the extra depth of 1,000 feet or so which necessitated the great difference in weight and strength, but the nature of the strata met with, which at Pittsburg must have been extremely hard or otherwise difficult to deal with. The comparison is certainly much in favour of Australian operations, present and prospective:—

"The deepest well ever drilled in America has been put down recently at West Elizabeth, Pennsylvania, 12 miles from Pittsburg, to a depth of 6,000 feet. It was started 100 feet below the Pittsburg coal vein. There was only one string of casing in the well, it being 6¼ in. and 900 ft. deep. At the depth of 2,285 ft. a flow of gas was struck which was sufficient to make steam to drill the rest of the hole. At 5,500 ft. the temperature was 129 degs. At that rate, the heat equal to the boiling-point of water, 212 degs., would be found at a depth of 9,000 feet. To drill this well it was necessary to have extra-heavy machinery. They used two 25-horse-power engines, two 25-horse-power boilers, three bull ropes, 16-in. belt, 13½-ft. band wheel, 5-in. forged shaft and crank, 4½-in. flanges, two brakes on the bull wheels, and two cables spliced together, making about 6,000 ft. One cable, 2¼ in. in diameter and weighing 5,600 lbs., was used at the bottom of the well, and the cable that

was used at the top of the well was 2⅞ in. in diameter, and weighed 8,400 lbs., making the total weight of cable 14,000 lbs. (= 6 tons 5 cwt.). The tools used to drill with were of the ordinary size. The cost of the well approximated £8,000.''

It will be noticed that this boring was carried out entirely with a cable in lieu of poles, as in the Canadian system. In the boring at Bimerah, Queensland, a cable was used to complete the work.

SUB-ARTESIAN WATER SUPPLY

There can be no doubt that there are immense accumulations of water in the rocks and sands of the crust of the earth. Very little of that crust is, in fact, impermeable to water, whether it be by absorption or by pressure from above. What may be the actual quantity of water contained in the earth's crust must remain an unsolved problem. It has been estimated by the noted French astronomer M. Flammarion to be sufficient to cover the surface of the earth to a depth exceeding 3,000 feet, and equal in total volume to one-third of the ocean water of the globe. The passage of water into the crust of the earth has been going on for ages, ever since the cooling of the crust began. The water has, by gravitation, forced its way through the minute interstices of the strata, and it moves laterally through those strata in all directions, until it meets a watertight wall or bed, or finds a vent at the lowest level attainable in the shores or the bed of the ocean. A very large portion of the rainfall—the source of all supply—sinks out of sight into the earth in so imperceptible a manner that it fails to impress itself on the mind.

Whatever the interior of the earth may be, whether solid or fluid, or partially so, the crust is porous. Even the hardest rocks are so constituted; granite itself has a percentage of water in its composition,

although water will not pass freely through it. All the softer rocks, especially those of alluvial origin, are water-bearing. The dense, compact limestones frequently hold great quantities of water, and they must be considered water-bearing, as they are much traversed by crevices at the surface; and rain water, acting as a solvent, has formed in them those huge caverns and underground conduits seen in the limestone caves, notably in New South Wales, Queensland, and Western Australia, and in the limestone reservoirs discovered in the Northern Territory of South Australia. Many good flowing wells have been obtained from this formation; but, where the limestone beds are deeply buried below watertight strata, they have not, so far as general experience goes, proved productive. Speaking generally, the only reliable sources of sub-artesian water lie in the numerous successive deposits of alluvial strata, the sands and gravels interspersed with clay or shale.

There are many districts in all the Australian States in which valuable sub-artesian or shallow water has been proved to exist, and is now awaiting further utilisation. Many of the stock and coach routes are supplied thereby. In the coastal districts over most of the continent there are great areas of alluvial deposit lying in the "flats" adjacent to and between the coastal rivers which are full of water of the best quality, 20 to 50 feet down. These waters will prove of inestimable value to dairymen and others, under increased settlement.

Sub-artesian water lies, as a rule, in the sands and gravels and newly-formed soft rocks of the Post-Tertiary or newest upper formations. A very large

portion of the rainfall has sunk into this formation, and is lying conserved therein.

The following is a description of actual work performed under my own superintendence, and its results in obtaining a sub-artesian supply.

The scene of my operations—and it may fairly be taken as a representative Australian one—was that of the head of the Barcoo, Birkhead Creek, Central Queensland, on the southern side of the ranges running west, and consists of rolling downs, through which the usual creeks have made their way. The geological formation (which may be taken as water-bearing) consists of sandstone, dipping from the ranges to south and west.

The "weathering," or disintegration, of the ranges during ages of time has formed, by the action of running water during the same period, large deposits of sand in great, wide, flat stretches of country, which were formerly valleys between successive ridges, now showing above the sandy flats, the lower part of which has been turned into porous sandstone, overlaid by a loose sand deposit, with seams of clay. It was in the porous sandstone that the large supplies of this shallow water were obtained. "Soakage," or first water, was met with in the loose sand deposits, at depths of from 6 to 35 feet. This was entirely shut off by watertight artesian tubing, and the second, or permanent water was struck in the porous sandstone at depths of from 17 to 90 feet. Drilling was continued up to 120 feet, thus ensuring a full supply. A 4-inch cylinder pump (the casing used being 6 inches inside diameter) was used at each bore for testing the supply, the tests being made after a long

period of dry weather. After continuous pumping for days the water level was not lowered, but, on the contrary, the supply was increased as the pumping opened out the water seams in the porous rock, and thus increased the flow. The capacity of the pumps, when worked, as they are, at a great many similar bores on the Darling Downs, by windmill power, is at the lowest discharge 15,000 gallons per diem. The pump, worked by two men, threw 900 gallons per hour at these Barcoo bores. In cases where windmill power is not available, the modern oil engine is a most efficient and economic substitute.

A belief prevailed in the Barcoo district that no "shallow" water—*i.e.*, within 100 feet of the surface—could be aught else than "soakage" from the immediate surface, and that during drought it would yield no reliable supply. This belief was, however, very successfully combated by shutting off the soakage with watertight artesian tubing, and so leaving the bores perfectly dry until the second, or permanent water lying in the porous sandstone was struck at from 40 to 100 feet. The level of these waters has not become lowered during many months of dry weather. If there were any connection whatever between the soakage water and the second water, the latter would rise to the level of the former. The fact that it has not so risen is conclusive proof that the two waters are distinct. Moreover, the soakage lies in loose, fine silt and drift; wherever this water could run, it would carry this silt and fine sand with it, and if it had found its way into a sump, or bore-hole, below its level, that hole would soon—in a few hours at the outside—be silted up. That these holes did not silt

up, but that each bore plumbed the same, to an inch, some four months after its completion, is a further proof that the lower water comes out of the porous sandstone lying below the level of the bottom of the tubing, which tubing was inserted to shut out the loose sand and drift. The tubing was forced down through the stiff clay seams lying below the sand deposit, and into the top of the sandstone.

In another boring at Cooper's Plains, Southern Queensland, perfectly good water was obtained by me at a depth of 82 feet only, the water rising to within 8 feet of the surface. The strata passed through were hard sandstone rock, carbonaceous shale, and some 17 feet of compact, tenacious brown clay, at the bottom of which, in a sand-drift, the water was struck. The watertight clay prevented all possibility of the water being simply soakage. The water had come from a long distance to the site of the boring, and the height to which it suddenly rose indicated very considerable pressure, which was undoubtedly due to a large body, or run, of underground water extending continuously to the ranges or the higher land of the Downs.

Previous to making these bores, shafts had been sunk in the beds of, and near, creeks, and were failures, because, on getting to the first, or "soakage," water, the strong, loose sand-drifts—which artesian tubing effectually shuts off—could not be got through by a slabbed shaft.

Other notable borings were those made by me on McFarland Bros.' Langawirra Station, 95 miles west of Wilcannia, Darling River, New South Wales. The country travelled over from Wilcannia was, for a long

distance, very forbidding, consisting of granite peaks, sand, and spinifex, but finely-grassed, level plain country was finally reached, which was taken up for improvement. The plain was evidently an alluvial deposit, and, on boring to a depth of 180 feet, very fine water was struck, which rose, under considerable pressure, to within 30 feet of the surface. The strata were clay, shale, clay again, and then porous sandstone and drift. I wrote to the local paper at the time, describing the indications, and urging deeper drilling for true artesian water, but it was not until many years afterwards that artesian flows were obtained, either by the Government or by pastoralists, in that district. It is now within the acknowledged artesian area of the State.

Grit is a descriptive term for this sub-artesian water-bearing formation, and it varies in its nature. In places it encloses a fine powder, which is largely siliceous, and appears to be of volcanic origin. Elsewhere the grit is an aggregation of sand and lime. Then there is the mortar form, enclosing pebbles, quartz, feldspar, diorite, and other igneous rocks. Then the lime matrix almost disappears, and we have a heavy conglomerate of water-worn pebbles of the rocks above mentioned, with jasper, quartzite, and agate. The conglomerate changes at times into beds of a fair quality of water-bearing sandstone. There is no doubt that this Tertiary grit exists under very extensive areas in New South Wales, South Australia, and Queensland, especially in the first named, and that its character for holding water is continuous in many of those areas. On level country it is covered up by a deposit of Tertiary marl, which tends to hold down

the accumulated waters in the grit. The marl varies from 20 to 200 feet in thickness, and the grit from 20 to 100 feet. Wherever there are natural springs, they are from the grit; *and many of the springs might be tapped above their present outlet, and their waters made available for gravitation irrigation.*

Many of the creeks of the interior are kept flowing by the abounding waters in the Tertiary grit. The creeks are merely evanescent flood channels until they are cut down below the grit, and then their channels have a larger flow, except where hidden in sand, which is largely the debris of the grit.

The sandy nature of formations—which in a large part of the downs or plains regions are noted for their water-bearing capacity—is the main cause of the conditions which allow some of the creek valleys to have a sub-flow of water equal to, or perhaps greater than, that of the visible creeks. The conditions of hydrostatic pressure under which the sub-flows exist suggest that the movements are directly related to those of artesian wells and springs.

Means of increasing this shallow-water supply have suggested themselves to me, after many years of close study in this country of the practical operations, and bearings, of boring for water. One of these is the feasibility of conserving a large amount of the sub-flow described above by forming sub-dams in a deep trench excavated in a dry season across the bottom of creeks, so as to prevent the passage to waste of a large quantity of sub-flow from the upper reaches in their vicinity. This sub-flow from large areas of country now finds its way to the lowest level attainable, the bed of the creeks, and passes away.

If it were intercepted by a low-level sub-dam, it would remain penned up in the ground, and thus maintain a larger and more constant supply for bores in the vicinity to draw upon. It is a common practice to dig for water in the sandy beds of dried-up creeks. The water may be found at first at a few feet below the surface, but in a few weeks' time, or less, a greater depth is necessary to reach it. As evaporation could not have so reduced the water level, it is clear that the level, in the bed of the creek, and also in the adjacent country, must have been reduced by drainage of the water laterally to lower levels, and, in many cases, finally out of the reach of shallow boring.

These conditions are found especially to rule throughout the mountainous portion of the arid regions. The creeks which flow through valleys or narrow gorges have, as a rule, filled up their beds. In ancient times the streams cut their way downward into the solid rock to a depth considerably below the present creek channels. In modern geologic times these ancient channels have become filled to a depth of 10 feet, 20 feet, or even 100 feet or more. The material usually consists of large boulders, with occasional beds of gravel, sand, or even clay, left in protected nooks. If this mass of material partly filling the gorge is dry, and a heavy rain occurs above, the water from the storm will flow down, saturating the surface, and gradually penetrating the lower layers until the spaces between the pebbles are filled. If the stream continues to flow for several hours, a considerable part of its volume may be taken in by the gravel, and the water may entirely disappear in the

course of a mile or two, leaving the surface dry. A creek cannot continue to flow undiminished over a boulder bed until the latter is completely saturated with water. A little consideration shows that if water is withdrawn from the pervious material beneath the surface of a creek, it must be replenished, and that the surface discharge is reduced by the same amount. A good instance of these conditions is the Bathurst (New South Wales) water supply, taken from subterranean flows far below the Macquarie River bed.

The water saturating the gravels tends to move downward and forward, under the influence of gravity; but its rate of flow, being diminished by friction, and by adhesion to the surfaces of the grains, is far less than that of the water on the surface. While the latter may be travelling two or three miles in an hour, the moisture underground, even in coarse gravels, probably does not pass over this distance in a week or a month. The rate of flow has not been determined, but a few experiments made in different parts of the country show that this rate is, under ordinary circumstances, extremely slow.*

The accompanying illustration (Fig. 4) is intended to show how the sub-flow in narrow valleys has been utilised. An impervious dam, the top of which is shown in the figure as being above the surface, is made to bed rock, and the joints at the bottom and sides are made watertight. Thus all the water percolating down the gravel and boulder-filled channel, meeting this obstruction, is retained, and, accumulat-

*See " Ocean Outlet and Discharge," page 66.

ing, may appear upon the surface. A pipe through this dam will draw off the water; but, to receive the largest supply, it must be placed near the bottom of the dam, and not near the surface, as shown in the drawing.

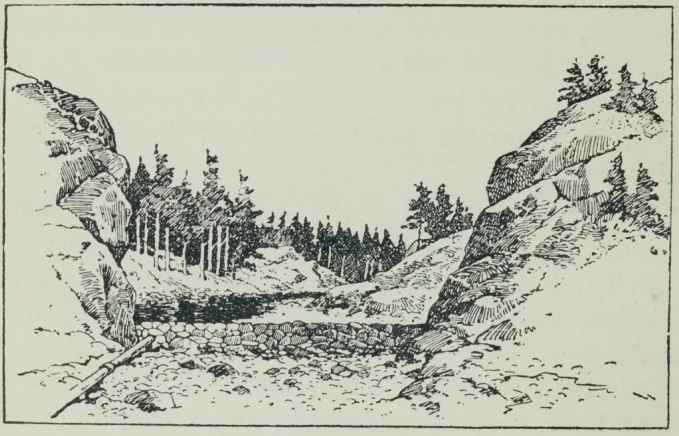

Fig. 4.—Dam across a rocky valley, cutting off the sub-flow.

Tunnelling for Water.—Tunnels are sometimes driven in sloping or sidehill country to tap the subterranean water supplies. These are practically horizontal wells, differing from ordinary wells chiefly in that the water has not to be pumped to bring it to the level of the surface, but finds its way by gravitation to the lands on which it is to be utilised. Near the Khojak Pass, in India, there is a great tunnel of this kind. It is run near the bed of a stream into the gravels for a distance of over a mile. The slope of the bed is 3 in 1,000, its cross-section is 1.7×3 feet, and its discharge about 9 second-feet (5,832,000 gallons) per diem.

The Ontario Colony in Southern California derives its water supply from a tunnel, 3,300 feet in length, run under the bed of San Antonio Creek, through gravel and rock. Its cross-section is 5 feet 6 inches high, 3 feet 6 inches wide at bottom, and 2 feet wide at top. It is partly timbered and partly lined with concrete, having weeping-holes in the upper part of

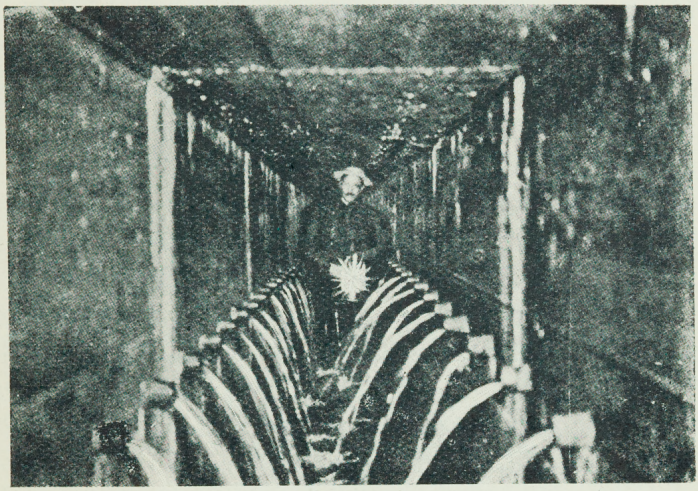

Fig. 5.—Subterranean Water Tunnel and Feed Wells, California.

the tunnel. Its discharge is about 6 second-feet (2,700 gallons) per minute, or 3,888,000 gallons per diem.

The Spring Valley Water Company, which supplies San Francisco, California, has recently made some of the most extensive developments of water from subterranean sources yet recorded. One bed of gravel in a stream valley, having an area of 1,200 acres, ab-

sorbs practically all the drainage of 300 square miles. Into these gravels were sunk 91 wells, which yield 36 acre-feet of water (equal to 9,753,948 gallons) per diem. Another similar bed has been developed by driving over 14,000 feet of tunnel 5 feet 6 inches by 5 feet 6 inches, with nearly as great a length of smaller branch tunnel. Into this drain several hundred wells were driven (Fig. 5), which yield over 45 acre-feet (12,192,435 gallons) of water per diem.*

Other Subsurface-Water Sources.—Earth waters may be gathered for irrigation by other means than springs, common or artesian wells, or tunnels. In portions of the plain regions of the United States, especially in Kansas, subsurface supplies have been obtained by running long and deep canals parallel to the dry beds of creeks or in low bottom lands and valleys. These canals, acting like drainage ditches, receive a considerable supply of water, and lead it off to the lands. In some experiments made on two sub-canals in Kansas the amount of water was 15 second-feet (6,750 gallons) per minute (equal to 9,720,000 gallons per diem) for each mile in length of excavation, which was carried to a depth of 6 feet below the subsurface-water plane. It was found that the depth and length were the controlling factors, the breadth of the canal having little effect on the amount of water entering. It was also found that the increase of flow as the cut was deepened was nearly as the square of the depth.

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* 1 second-foot = 450 gallons per minute.
1 acre-foot = 43,560 cubic feet, or 270,943 gallons.
1 second-foot = 2 acre-feet in 24 hours (approx.).

Looking at these object-lessons from India and America, it will be obvious that there are in all probability—as I have pointed out—enormous quantities of water equally available in the Tertiary, or Upper, formations of Australia. The deeper, or artesian, supplies naturally command a monopoly of attention; but these Tertiary water supplies, now lying hidden, and only awaiting development under scientific expert advice, will prove of very considerable value, especially under the closer settlement system, which the lands policy of the country seems to indicate.

There must be, in fact, enormous quantities of water in the Tertiary formation. The laws that operate in producing the deeper artesian accumulation apply in filling the upper porous strata. The deeper waters have their source mainly in the outcrop of continuous sheets or layers of porous rock, which were, as alluvial matter, deposited in the bed of a quiescent primeval ocean, and have since, with other strata, been subjected to geological upheavals and depressions. Some of the rain only that falls passes into the outcropping artesian rocks. A very large proportion falls on the general surface of the country, and sinks into the Tertiary formations—the grits—which lie in local sheets or layers, frequently of large area, on the top of clay or other impervious strata.

Such is the general nature and condition of the shallow water-bearing formation. In many localities much of this valuable shallow water is obtainable by drilling through apparently unpromising strata, such as basalt. There is no better example of this in Australia than that afforded by the Darling Downs

in Queensland. That volcanic action from ancient craters in the Toowoomba Ranges emitted, at one time, molten lava, which took its course along the beds of rivers then existing on the surface, has been proved by the great number of sub-artesian bores made in the Downs country within the last 25 years. A great number of these bores made by myself have clearly delineated the direction and width of the ancient rivers, and it is now well known that water is almost invariably met with in drilling through the basalt, or "blue stone" to the drift and water-worn gravel of the ancient buried watercourses. Before these pioneer boring and drilling operations began on the Darling Downs, there was much scepticism regarding getting water through the "blue stone." The formation was looked upon, not only as too formidable in texture, but also as too unlikely an element for water-bearing country. The fact that it was merely an accidental deposit, which had filled up the former river and creek channels, was little dreamed of until the borers, with their wider experience and their drills, settled the question.

In many localities, also, water has been obtained by drilling through layers of hard limestone, hard, dry sandstone, or tough, compact shale—a most forbidding stratum—to a depth of from 80 to 200 feet to the bed of buried creeks, clear evidence of which was shown by the sand-pump bringing up sand, gravel, and water-worn pebbles, and even native-made stone implements, from these ancient watercourses, which were still in active operation as of old.

Many shallow bores, from 80 to 200 feet in depth, give true artesian "flowing" wells, and since the

adoption of deep-drilling, and our consequent greater knowledge of the strata, this has been quite common on many stations where the boring has been done near the outcrop of the artesian rocks. In many shallow bores the water has risen to within a few feet of the surface, so that, by cutting a channel to lower ground, the bores have become "flowing" wells.

The proper location of sites for shallow bores is of the greatest importance. Too much guess-work has hitherto prevailed. An apparently simple subject, it is, like many others, beset with many ruling considerations—with the "science of practice"—which are foreign to an ordinary observer. In fixing upon sites for the deeper artesian bores, maps made by the Geological or Water-Supply Departments, from data afforded largely by the bores carried out, furnish valuable information; but, in regard to the Tertiary, shallow, water-bearing country, although likely districts may be indicated, many necessary data must be obtained by the well-borers themselves. In examining country, reliance must be placed upon surface indications alone—viz., the lay of the land, the kind of tree growth, the outcrop of rocks and their kind; the surface formations, and rocks partially disintegrated or entirely decomposed; the proximity of creeks, valleys, and low-lying depressions; and the average rainfall of the district. It has been found that, given the general surface indications, as described, a well-borer of long experience, by utilising his knowledge and the intuition which has become, by a slow but sure process, natural to him, can locate boring sites with an almost absolute certainty of success; and that, in cases where the strata he meets

with do not promise well, he knows when to stop expenditure, and to try again further on.

As it may appear remiss not to mention that long-lived perennial mystery, the "divining-rod," in connection with locating subterranean water, especially the shallower, it will be well, without entering into a philosophical discussion of the subject—if, indeed, its nature would admit of doing so—to call attention to one important fact—viz., that the "science" has not established itself on an acceptable footing in Australia (which has presented a magnificent field for experimenting in), although its professors, past and present, may be counted by scores, and have had every encouragement and facility repeatedly afforded them, to prove their position.

The notion is a very old one, and has had ample time to permanently establish itself if its value were equal to its pretensions. We should, in fact, doubtless have had, ere this, Government "divination" experts to further facilitate our researches for an increased water supply, and to determine the actual boundaries of the areas of underground water, the delineation of which will, I am afraid, have to be left, mainly, to the skill of the borers and their drills.

Machinery.—The question of the best mechanical means of getting this shallow water is one which practical well-borers, with a large experience in this country, have, I believe, now set at rest. My own decision has been arrived at after many years of practical work and study in 31 districts of Victoria, New South Wales, Queensland, and Western Australia—mostly in Queensland—in boring on stations, and for farmers and for railway purposes, part of the work

having been done for the Governments of Victoria, Queensland, and Western Australia respectively. Various types of machines, both of English, American, and Australian make, have been used, all of which have, from time to time, been placed in my charge. I think it will be generally admitted that none of them has proved an unqualified success, principally because their parts were too many and too complicated, and their movements consequently not simple enough either for boring in alluvial ground or for drilling in rock. Moreover, they were too liable to breakages in transit and working, or to some hitch or other in the complicated mechanism, which require a skilled mechanic to make frequent repairs, and cost much more than can usually be afforded for the purpose in view. No one will dispute the mechanical skill and ingenuity displayed in their design, but the conditions of work in the bush have a law unto themselves, and are very different from those of work in a town or its suburbs.

The simplest, most effective, the quickest in drilling in rock, and by far the lowest in cost, is a plant made with improvements on the " spring-pole " principle, with a spring pole for drilling in rock, and with hand-boring rods for alluvial strata.

Spring-Pole Plant.—Figures 6 and 7, illustrating the spring-pole plant, show a side view and an end view of the derrick, the borer to start the boring, and the rock drill at work. The derrick consists of three poles of bush timber, 20 ft. long, 5-in. butt, with a bolt through at the top, to which are slung a large and a small block pulley, working at right angles to each other, for the drill and the sand-pump ropes respec-

tively to work through, from a large winch and a small winch at the foot.

The boring, on commencing the bore, is done with ordinary square wrought-iron boring-rods, 1¼ in. in diameter, until hard ground is met with, when the drill is used. The boring-rods are turned by hand-spanners, and are lowered and raised by the large winch, the rope from which passes over the large pulley at the top of the derrick.

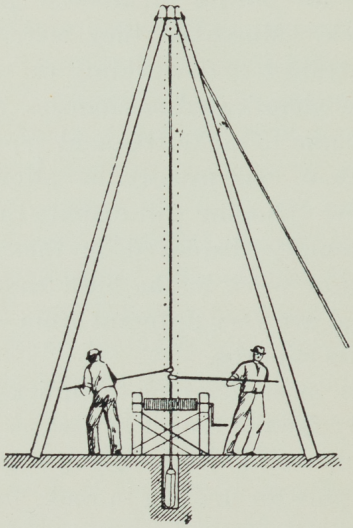

Fig. 6.—Boring in Alluvial.

The drilling is done by means of a spring-pole, 25 ft. long, 5-in. butt, preferably of lancewood, iron-bark, or any elastic hardwood. The butt end of the pole is tenoned, and inserted, 10 ft. from the ground, into a hole to fit it cut in a tree, or, failing that, into a vertical log secured to a cross ground log. At

8 ft. from the butt end the pole rests upon a trestle, also of bush timber, as shown in the diagram, the height of the trestle being 10 ft., which throws the working end of the pole higher than the butt. A short hanging rope, with a cross-piece of wood, forming handles for one or two workmen to pull down upon, is attached to the pole at the working

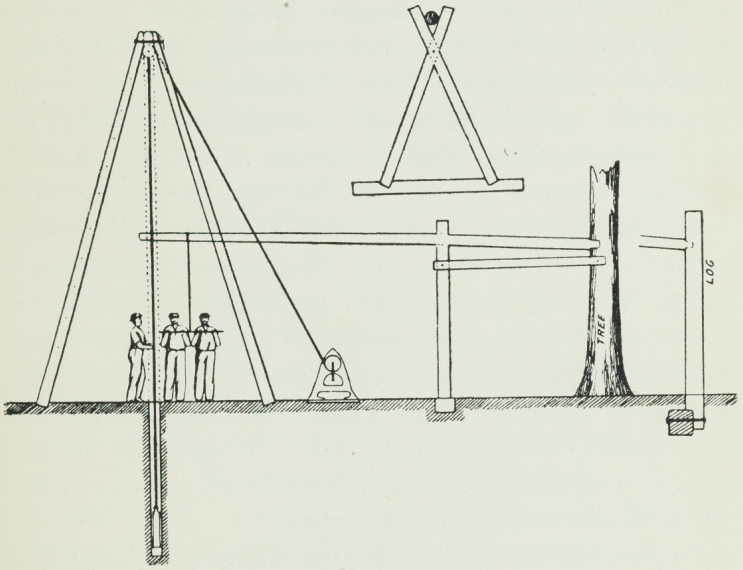

Fig. 7.—Rock-Drilling.

end. Another short rope, also attached to the same end of the pole, over the bore-hole, has an iron rope-clamp at the end of it, level with the cross-piece. In drilling in rock, after the cutting chisel or bit has been lowered to the bottom of the bore-hole by the large winch, the end of the pole is pulled down; the drill is then clamped on to the short rope hung to the end of the pole and the end of the pole let go,

when its back spring lifts the drill, the movement being kept up by one or two workmen pulling down, with little exertion, the end of the pole, and again releasing it without letting go the handle.

Provision is made under this simple system for any requisite power of spring, lift, and drop, and the force, speed, and number of blows per minute (regulated to a nicety by the workmen) is greater than in any other movement — not excepting that of deep artesian machinery — I am cognisant of, or can conceive. After carefully noting the working of the various other shallow-boring machines in use in the movements for lifting and dropping the tools in drilling, I have found this spring-pole movement gives from 40 to 50 per cent. more blows per minute than any other; and it is therefore the most economical in practice, and is by far the simplest in construction and working. The spring of the pole, being *direct* from the bearing on the trestle, is extremely sensitive, and the blows can, as pointed out, be adjusted in every way, with the greatest nicety and precision.

In rock-drilling with other machines, the power has to pass from the shaft through cogged wheels, levers, pulleys, etc., before it operates in lifting and dropping the chisel, and in "tightening up" or "recovery" after a blow has been delivered, in order to give another one. The spring-pole, on the other hand, lifts and drops by its own action and spring, direct within itself, the power applied being that of one or two workmen in starting and keeping up, with moderate exertion, the movement; and no steam or horse power is required.

A "sand-pump," consisting of a 5-in. tube, with a valve at the bottom, for drawing up the cut rock and cleaning out the bore-hole, is worked from the small winch. The large winch is an ordinary quick-movement contractor's winch, with a brake attached for quickly lowering and raising the drilling-bit. The small sand-pump winch is made of bush timber, the ironwork only being supplied. The working tools for rock-drilling are identical, in every particular, with those used in deep artesian drilling, excepting that they are lighter. They consist of a chisel, or bit, rimer, sinker-bar, jars, undercutting tool, eye-piece for drill rope attachment, sand-pump, ground clamp, and clamp spanner for lifting, lowering, and turning the tubing, and casing-cap for driving the tubing (if required). The tubing used is the ordinary swelled-joint 6-in. artesian, the cost of which at the bore would be about 4s. per foot. The tubing is perfectly watertight, and may be obtained "slotted" —that is, with slots cut in the bottom length, to admit water freely in coarse water-bearing strata. An important feature of this apparatus is that, from its extreme simplicity, the timber-work—*i.e.*, derrick, spring-pole, trestle, and the sand-pump winch—can all be made in the country of bush timber, the carriage and liability to breakage in transit being thus saved and avoided. The weight of the winch, and all ironwork, including boring-rods for, say, 30 ft., complete set of working tools, ropes, etc., is about 1½ tons.

Hints for Working the Plant.—First make a small platform of bush timber, adzed, notched, and spiked, square in shape, with a square opening of 18 in. When

set in the surface over the bore-hole, it will act as a rest for the boring-rods in uncoupling and coupling and will preserve the surface at the top of the bore-hole. If the boring becomes at all hard, even in clay, shale, etc., the jumper chisel, spring-pole, and sand-pump may be used, provided a little water is sent down. It is, in fact, practicable, although not always the most economical, to make the whole bore by jumping with the chisel and sand-pump. If the bit sticks in drilling, a quick release movement of the spring-pole acting on the jars will loosen and free it. A frequent use of the rimer to keep the bore plumb and round is of *the greatest importance.* Frequent riming is generally neglected, at the cost of really quick and economical work. It is no use sending down the chisel if the bore-hole at the bottom is not in a fair condition for work. The rimer, by frequent use, ensures such condition; and *it pays to use it.* In putting down the tubing or casing, if it will not go down freely, by its own weight, after boring or drilling below the cutter ring or shoe, the casing clamp should be screwed on and the casing turned by the hand-spanners used in boring. If the casing will not go down with turning or undercutting, it must be rammed down by making a ram of a log about 15 in. in diameter and 5 ft. long, slung on to the drill rope, and lifted and dropped by the workmen. The casing-cap, screwed on to the top of the casing, prevents the screw-end being injured by the ram. In loose, sandy strata, quick sand-pumping—as quickly as the pump can be lowered, raised, emptied, and lowered again—is the only way of getting casing down in wet sand. Wet sand—the bugbear of borers

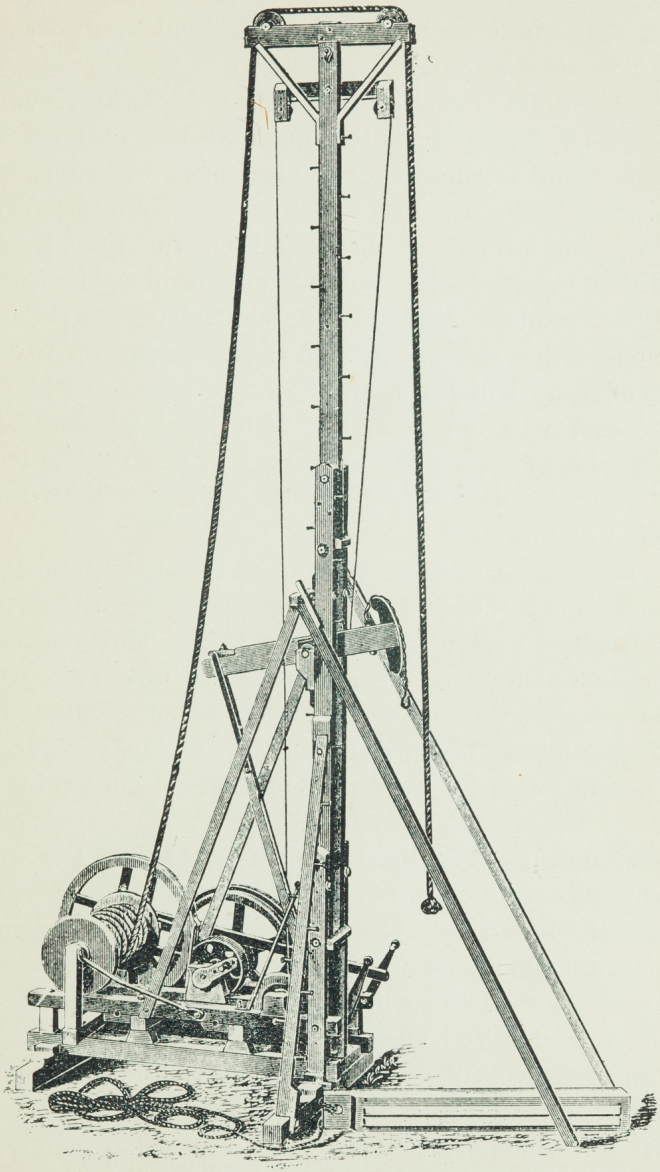

Fig. 8.—Portable Drilling Rig.

and shaft-sinkers—has a tenacious hold upon casing, both inside and out.

The simplest mode of obtaining the quickest pumping is by fixing a snatch-block at the foot of the derrick and letting a horse, hitched to the rope, run out and back, to raise and lower the pump. The horse can, of course, be also used for raising the drilling tools. If the pole, after considerable work, takes a camber—that is, if its elasticity becomes lessened—either reverse it, lash a half-timber on to the top of it, or, which is best, put a new pole in its place. The cost will not be much. The spring-pole plant is capable of good work to a depth of at least 200 feet. At a greater depth the next best system is that illustrated in Fig. 8.

This is a portable machine, and is adapted to drill wells from 200 to 1,000 feet. Power is applied to the band wheel by a belt from an engine. The sand reel is operated by friction, applied by a lever; the bull wheel by friction, or a chain, and clutch. These rigs are simple and easily repaired, and as inexpensive as is possible for the work they are capable of performing.

Windmills.—The most important and widely distributed source of power for pumping water is wind. Over the broad valleys and plains of the arid region, the wind blows, as a rule, without ceasing for days and weeks. In many localities there are, as shown, at moderate depths beneath the surface, porous beds of sand or gravel filled with water by the infiltration of rainfall or by percolation from creek channels.

It is a comparatively simple and inexpensive operation to sink a well or bore into this water, and erect

a windmill, attaching this to a suitable pump. The machinery, once provided, is operated day and night by more or less wind, bringing to the surface a small but continuous supply of water. This small stream, if turned out on the soil, would flow a short distance and then disappear into the thirsty ground, so that irrigation directly from a windmill is usually impracticable. To overcome this difficulty, it has been found necessary to provide small storage reservoirs or tanks, built of earth, wood, or iron, to hold the water until it has accumulated to a volume sufficient to permit a stream of considerable size being taken out for irrigation. Such a stream, flowing rapidly over the surface, will extend to a distance, and cover an area which would seem impossible with the small flow delivered by the pump.

In building these windmills, pieces of old mowing-machines or reapers have been used for axles, bearings, and connections. The sails have been made of pieces of old boxes or other timber around the farm, and the whole machinery stiffened and held in place by bale or fencing wire or other waste material found in quantities around the homesteads of men who have attempted to make a living upon the plains. Thousands of settlers in America have pushed westwards from the humid into the sub-humid portions of the arid region, and in years of abundant rainfall have been able to raise one or two crops. With the changing cycles of moisture, these regions becoming dry, the pioneers have lost their crops year after year, and have been compelled by starvation either to leave the country or to change their methods of farming. Under these circumstances, discouraged, without

capital, some of the more ingenious and persistent settlers have been able to dig wells, build windmills, and irrigate a small patch of ground, and, gradually adapting their methods to the climate, have improved upon their conditions, and made comfortable and permanent homes. The crude mill has then given way to the foundry-made mill, with its neater appearance and greater efficiency.

The accompanying figure (9) shows two of these mills placed on opposite sides of a small earth reservoir, into which water is being pumped for irrigation.

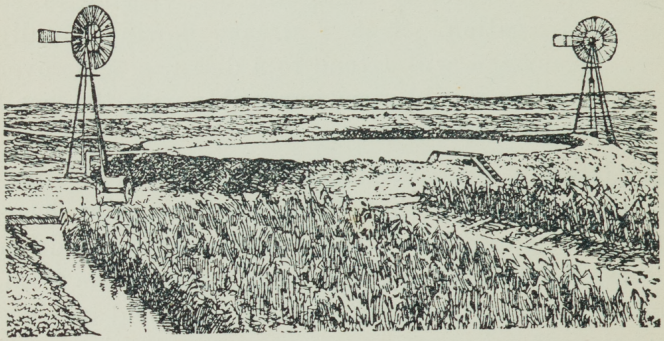

Fig. 9.—Windmills pumping into earth reservoir.

Sometimes as many as half a dozen mills are placed around a tank of this kind, a number of small mills being found better than one or two large ones.

When the diameter of the wheel is increased much above 10 or 12 feet, the strength is considerably diminished, and liability to injury during storm is greatly increased. Small, rapid-running mills, 8 or 12 feet in diameter, have, therefore, been found most economical. If one is injured, the others will usually continue pumping.

The disadvantage of windmills, as a class, is that most of them are constructed to operate only in moderate winds. The very lightest breezes often pass by without starting the wheel in motion. As the strength of the wind increases, the wheel begins to revolve, reaching greater and greater efficiency until the velocity is about 8 or 10 miles an hour. At greater speeds, the mills are usually so constructed that they begin to turn out of the wind in order to protect themselves, and thus the efficiency begins to drop off rapidly as the wind becomes more and more powerful. When it approaches a gale, the mill stops completely, and thus, at the time when, with sufficiently strong construction, the greatest amount of water could be pumped, the machine is standing idle.

One of the important inventions yet to be made is a simple, strong windmill which will continue in operation through a heavy wind. Many mechanicians have tried their hand at something of this kind, but have not yet succeeded in producing a commercial article. The suggestion has been made that pumping by wind may reach its highest efficiency through the use of compressed air, the windmill operating some form of simple air compresser, from which a pipe will lead down into a well, and through it water will be forced out by means of what is known as an air lift. If such a device is practicable, the windmills can be located on the highest point of the farm, and the compressed air be carried down to the lower-lying wells.

Among other systems of pumping from wells, such as by steam pumps or by machinery worked by gas, gasolene, oil, or hot air, the oil engine appears to be most in demand.

Oil Engines.—Very effective pump-power can be gained by the use of the portable oil-engine, which consists of base, cylinder, piston, connecting-rod, crank shaft, and fly-wheels. The way of working, and the development of power, are as follows:—In starting up, on the first outstroke of the piston, a mixture of air impregnated with the proper amount of gasolene is drawn into the cylinder, passing through the valve chambers. On the instroke of the piston, this mixture in the cylinder is compressed into the space between the cylinder-head and the piston. The combustible mixture is then ignited by the most reliable, safe, and simple device possible—a short iron tube closed at the outer end and connected to the interior of the cylinder, enclosed in a chimney, and heated by a burner; and, the air being expanded by the heat involved, an impulse is given to the piston. When the piston has reached the second outstroke, the exhaust-valve is opened, and remains open during the second instroke of the piston, and the products of combustion are expelled through the exhaust pipe, which is conducted to the outer air.

The great merits of these oil engines are that they require no attendance after replenishing with oil, and may be closed in and left to work regularly for days together with safety; and that they are independent of the vagaries of the wind, to which the windmill is subservient.

IRRIGATION

Irrigation—artificial water supply—has a history going back into the mists of time. There are reliable evidences extant that in the oldest Eastern civilisations the art was practised in a thoroughly scientific and efficient manner, which we moderns cannot hope to more than emulate.

The extent to which irrigation has already been practised is enormous. The total area irrigated in India in 1903 was about 33,000,000 acres, in Egypt about 6,000,000 acres, and in Italy about 4,700,000 acres. In Spain there are 2,800,000 acres, in France 400,000 acres, and in the United States of America 7,600,000 acres of irrigated land. This means that in these countries alone crops are grown on 54,500,000 acres of land which, but for irrigation, would be barren and unproductive. In addition to this, there are some millions more of acres cultivated by the aid of irrigation in China, Japan, Algeria, South America, and elsewhere.

It is a fair estimate that there are in the world to-day at least 200,000,000 persons depending solely for their food upon areas irrigated by water drawn, in the most primitive manner, partly from surface supplies, but mostly from underground sources, in the form of wells, springs, or drainage conduits. An examination of the records, habits, and customs of the communities so supplied will show an elaborate system

of maintenance. The countries in which this system has most widely obtained have in past centuries been more highly civilised, and have borne a large share in the ancient history of the world. But the constant aridity of climate has nullified the ameliorations produced by human industry; the conduits have been filled up, the wells choked, and the elaborate surface works destroyed, and a vast desolation has succeeded to the former expanses of cultivation. The re-establishment of the irrigating works (as in Egypt), and the conservation of the water supplies required therefor, will quite certainly restore enormous portions of these great areas to the use of man. If such things can be done in Central Asia and Persia, they can certainly be achieved under the milder general climate of Australia.

Although irrigation is known to be of incalculable benefit, the tendency of land-holders is undoubtedly to rely upon the natural rainfall—a supply which gives no trouble and involves no cost; hence any advice regarding an auxiliary artificial supply must be confined to the plainest and simplest modes, with their corollary of moderate cost.

Practice as an hydraulic engineer during a residence of six years in the United States of America—mostly in the western farming States—made me familiar with the irrigation methods there in vogue. That practice was based largely upon Mexican methods—which had been copied from the ancestral Spanish—with improvements to meet American conditions, which are almost identical with those ruling in Australia.

The following are descriptions of American irrigation as now practised. More space is devoted to crude, but effective, home-made contrivances than to elaborate or expensive machinery, because I found that the success at the outset of irrigation depends mainly upon the rough-and-ready ingenuity of the first settlers in a new country, in adapting their ways to the environment. The more elaborate and costlier modes may be safely left to a future time.

AMOUNT OF WATER APPLIED.

The most important factor in agriculture is the skill of the cultivator, and it is justly calculated that the limit to the development of his skill is not within sight. While methods of conservation, directing river water, and procuring artesian supplies have been developed and improved upon, irrigation proper—the application of the water to the soil—has been left to chance, and the experience hitherto gained has been mostly through costly experiments and failures.

Successful methods of leading water to plants requiring it are dependent upon the soil, crop, and climate, and especially on the knowledge and skill of the irrigator. The proper degree of skill can be acquired in two ways only—either by actual experiment, or through the teaching or writings of those who have by a long systematic study mastered the subject.

Prodigality in the use of water is the prevailing practice of farmers commencing irrigation. The idea ruling with them seems to be that the demand of the

languishing land and crops for water is proportionate to the shortage to which they have been subject during droughts. The ditches are therefore opened, and the land flooded and waterlogged, and the crops injured, if not totally destroyed. A useful lesson may be drawn from the practice of the Chinese gardeners, who, although they may have an ample water supply at disposal, irrigate their land with judgment, using the smallest quantity necessary.

The quantity of water needed to moisten the soil thoroughly depends on certain conditions,viz.: First, the nature of the soil; second, the character of the climate; third, the nature of the subsoil.

As to the Soil.—The retentive and absorptive powers of soils differ greatly. Those which absorb most water retain it the longest. Capillary attraction, or surface tension of the particles of the soil, regulates the power of absorption. The total surface of the particles of the finer soils being the greatest, those soils will absorb the most water, and will also retain it the longest. Thus coarse gravel will not retain water; pure quartz sand will absorb but little, and will soon part with it; while a fine alluvial soil will take in a large quantity and retain it a long time.

The following table gives the results of experiments made by Schübler to determine the capacity of different soils for water, and their comparative power of retaining it. In these experiments the different soils were thoroughly wetted with water up to the point of saturation, and the increase of weight noted; this is shown in the first column. In the second column are given the quantities of water which evaporated in

four hours, the samples of soil being spread over equal surfaces:—

	Percentage of water absorbed.	Percentage of water evaporated in 4 hours.
Quartz sand	25	88.4
Limestone sand	29	75.9
Clay soil (40 per cent. sand)	40	52.0
Loam	51	45.7
Common arable land	52	32.0
Heavy clay (20 per cent. sand)	61	34.6
Fine carbonate of lime	85	28.0
Garden soil	89	24.3
Humus (peat or decayed vegetable matter)	181	25.5

Therefore it will be seen that the greater the absorptive capacity of a soil the longer it retains the water. It follows from this that the quantity of water that will be required in irrigating any particular kind of soil will depend upon the soil's power of absorption. Experience has shown that a soil containing 20 per cent. of sand needs irrigation about once in 15 days, while under similar conditions, one which contains 80 per cent. of sand should be irrigated once in 5 days. A still greater difference is shown between soils still more diverse in character, and less with those which may be classed between these limits.

The quantity of water required, in addition to the rainfall, has not yet been fully determined for any kind of crop. Taking the generally accepted amount of 24 inches of rainfall as the amount required to mature a crop, it is only necessary to deduct the average annual rainfall from 24 inches, and the difference will be the amount to be supplied. One acre of ground requires 22,622 gallons of water to cover it one inch deep, and this amount multiplied by

the number of inches necessary to add to the rainfall, so as to make up the required 24 inches, will be the number of gallons of water per acre to be supplied.

An acre of water one inch in depth weighs about 113 tons, and to produce one ton of hay from three to five inches is required. To produce a crop, this amount at least is necessary, and sometimes much more. The actual amount used in producing five tons of barley-hay to the acre has been found to be about 20 inches. The permeability of the soil and its ability to hold water regulate the amount. In Southern California, which is liable to deficient rainfall many years in succession, there is—on account of the great demand made at those periods upon the water supply—the greatest economy in its use. The years from 1897 to 1900 proved that cultivation could be maintained on a very small supply of water. An amount not exceeding six inches in depth was found to be quite sufficient when led directly to the plants, if combined with proper tillage and clean-kept land. By means of thorough cultivation, nearly all sorts of fruits were raised without irrigation, although the quantity was less. The citrus fruits alone require plenty of water.

Various Water Companies in Southern California estimate that the quantity of water required to irrigate an acre ranges from one miner's inch to from five to ten acres—the miner's inch being a run of 11,109 gallons in 24 hours, or almost 0.02 second-foot (see Table of Measures, foot of page 116) delivered under a four-inch head measured from the centre of the opening. At this rate a second-foot would irrigate from 250 to 500 acres, provided the water were

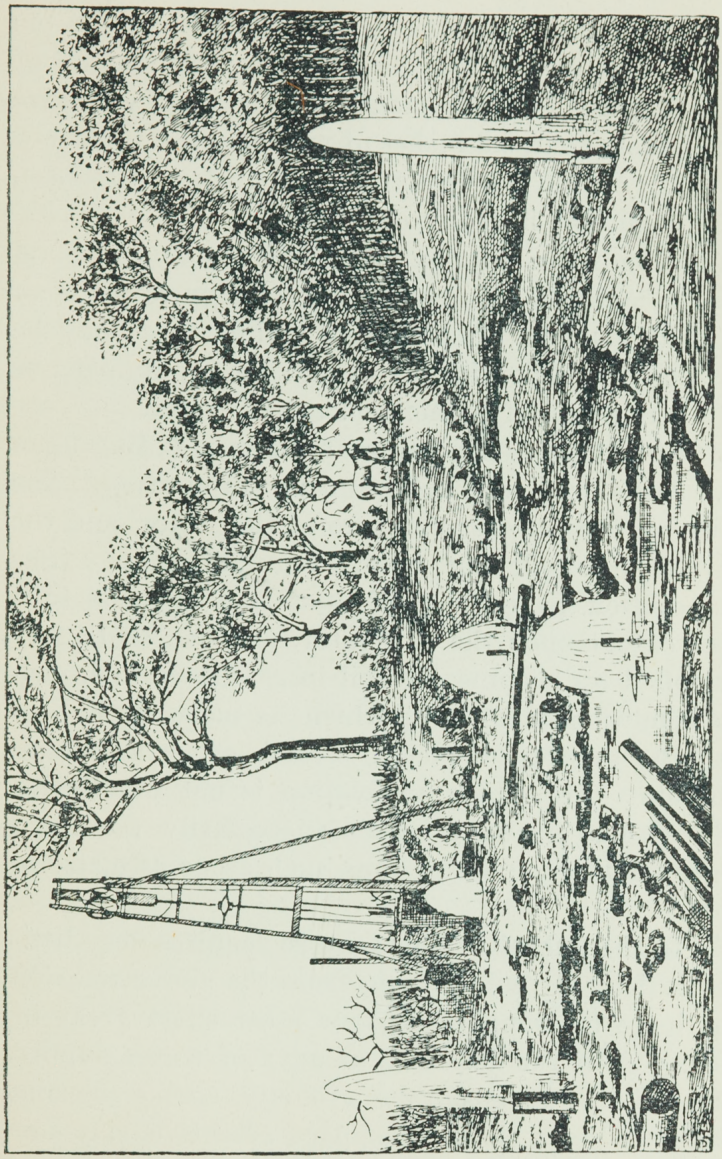

Fig. 10.—American Irrigation from Artesian Wells. Low-Pressure Wells, Southern California.

delivered in cement-lined channels or pipes. On the assumption that the miner's inch is sufficient for ten acres, or one-second foot for 500 acres, this amount of water flowing for four months in the year will give a little more than 8.8 inches of water on the surface—a quantity which, with careful cultivation, has been found sufficient in many orchards.

The conditions of Southern California (which, in physical and climatic senses, are similar to those of the arid portions of Australia), while they may be considered as exceptional, yet indicate the limiting or ideal conditions of economical use of water.

As to Climate.—A portion of the rain falling upon the earth's surface is taken up in evaporation. The nature of the soil, temperature of the water, and the prevalence of drying winds regulate this. (See Evaporation, page 155.) Evaporation depends to a great extent upon the cultivator. It can be largely controlled by keeping the soil in a well-worked, mellow condition of tilth, in which its moisture is held with the greatest tenacity. Such crops as wheat, oats, etc., with which cultivation is not practicable during their growing season, necessarily require a larger quantity of water than such crops as maize or roots.

As to the Subsoil.—This feature requires very little elucidation. It will be seen from the above remarks that loose or compact subsoils must exert great influence upon the requisite amount of water supply. Some soils lie upon porous, gravelly, coarse subsoils, which act like a sieve. Compact, retentive, clay subsoils, on the other hand, act quite the reverse.

Besides sunshine, soil, and water, there is another

element in production, viz., a low order of vegetal life known as nitrifying organisms. These, in combination with air and moisture, form plant food, carefully preparing it for consumption, provided the amount of moisture is properly adjusted.

Excepting to arrange the head gates, and to allow the water to flow to certain portions of the paddock, irrigation is usually carried on in the daytime. Night irrigation has, however, many advantages and advocates. The air being cooler, excessive evaporation is reduced or evaporation is entirely checked; there is less loss of water, and the plants are not suddenly chilled as they are during the heat of the day when cold water from river or reservoir supplies is used. Artesian water, being of a higher temperature, is far better adapted, in this respect, than are supplies from other sources.

Amount of Land that can be Irrigated depends, first, on the depth to water and supply of water in the wells; and, second, on the size of windmill, or other power, and pump used. And when general crops are grown, so that the pump may work the year round, larger acreage can be irrigated than when only truck-farming is done. The same pump will irrigate only one-half as much land when water is raised 40 feet as when it is lifted only 20 feet, and only one-quarter as much land when the water is lifted 80 feet as when lifted 20 feet.

When low velocities of wind are to be used (if windmill power be adopted), a smaller cylinder will have to be used, that the wind may be able to operate the pumps. A wind velocity below 15 miles per hour furnishes so little power, with any size of windmill,

that few persons care to utilise the force of such a wind in irrigation. Substantial windmills may be adjusted to work in a wind of 30 to 35 miles per hour, when the power of the wind is four to five times as great as when the velocity is only 15 miles an hour.

How to utilise this varying force is of the greatest importance to those who use windmill pumps. An irrigating windmill can make twice as many strokes of the pump in a 30-mile wind as it can in a 15-mile wind, and will, consequently, pump twice as much water; but, as its power is more than four times as great, working in a 30-mile wind as in a 15-mile wind, it should not only have doubled its work, but quadrupled it. Hence, it will be readily seen that, to utilise all the force of the wind up to the point the mill has been adjusted to, two or more pumps must be employed, and as many pumps may be connected as the mill can operate with the force supplied for the time being. A windmill working under the full pressure of 30-mile wind has power to lift eight to ten times as much water as when working under the force of a 15-mile wind. *The time to pump is when the wind blows.*

A complete windmill and pump irrigating plant will consist of one windmill and two or more pumps.

The reservoir should be constructed in an oblong form—*i.e.*, 50 by 100 feet, or 100 by 200 feet, and so on. Erect the windmill near the embankment on one side, midway between the two ends; this will allow you to work one or more pumps on each side of the mill, by means of quadrants, and the pumps will be close enough to the embankment to discharge water into the reservoir through short flumes or pipes.

IRRIGATION PUMPING PLANT.

Fig. 11 is an elevation illustrating a practical windmill irrigation pumping plant. An open well is dug through the super-strata as far down as the dry sand,

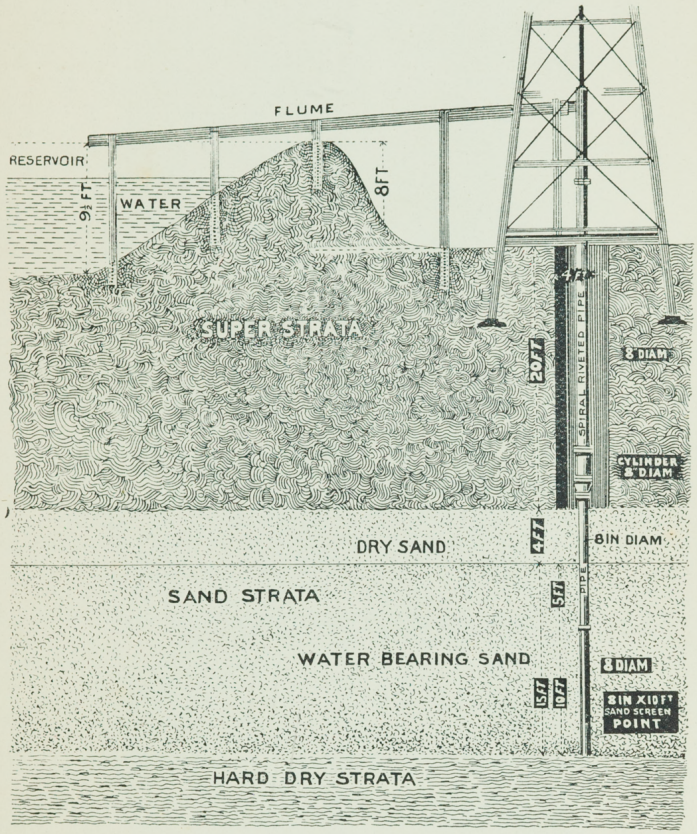

Fig. 11.

and a sand-screen point, which is a metal tube with minute perforations, is driven the rest of the way to hard-pan. The diagram also shows the best form

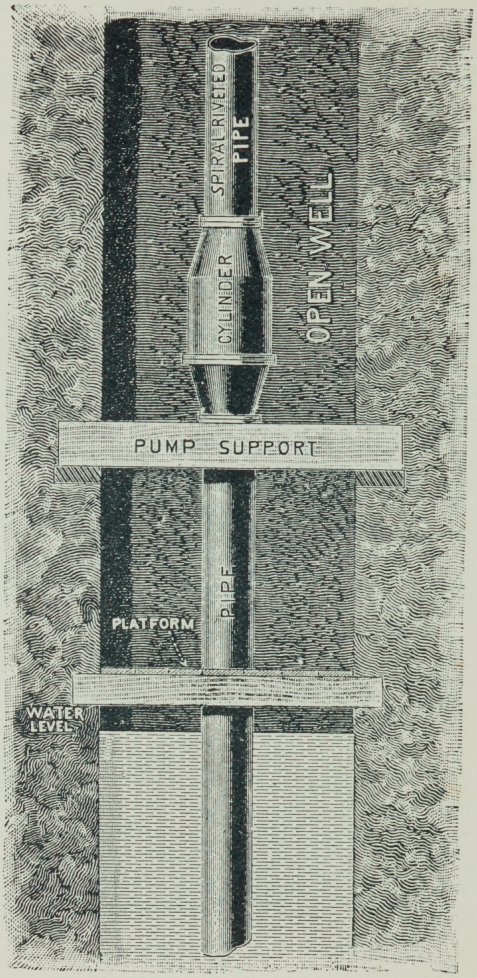

Fig. 12.—Pump Cylinder and Pipe as arranged in an open well.

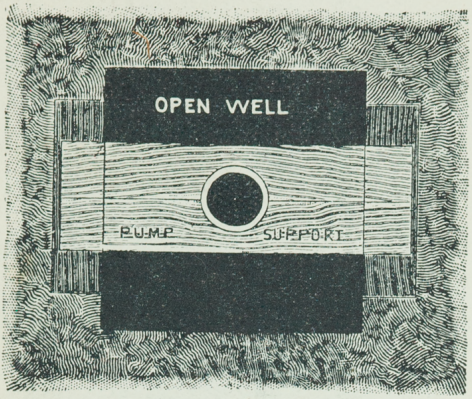

Fig. 13.—Top view of the Support for Cylinder.

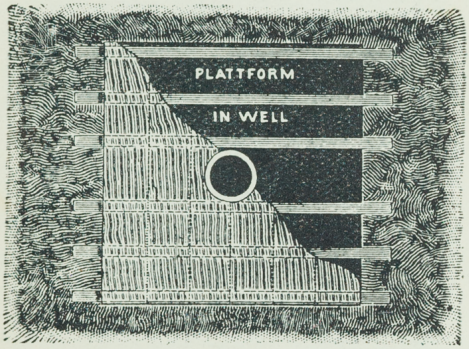

Fig. 14.—Top view of Platform below Cylinder and near the water. This Platform makes a convenient arrangement when any repair is to be made to the cylinder.

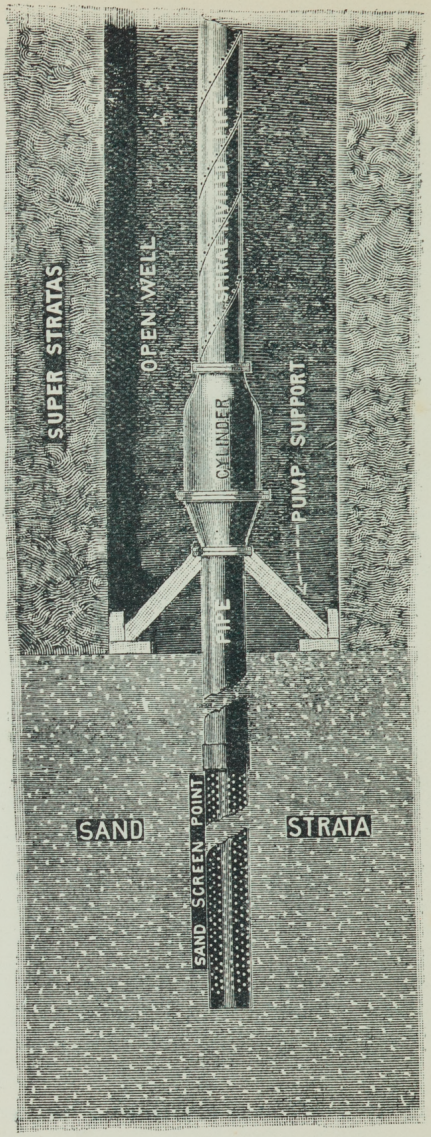

Fig. 15.—Side view of Pump Cylinder, used with Screen Point, and the correct method of bracing same to prevent its settling and then getting out of proper relation with the working parts of Pump.

of embankment to use for reservoirs, the arrangement of flumes for delivering the water from the pump to the reservoir, etc.

Open Wells can be successfully made in clay and stone strata, but as a rule are not successful where water is found in sand strata.

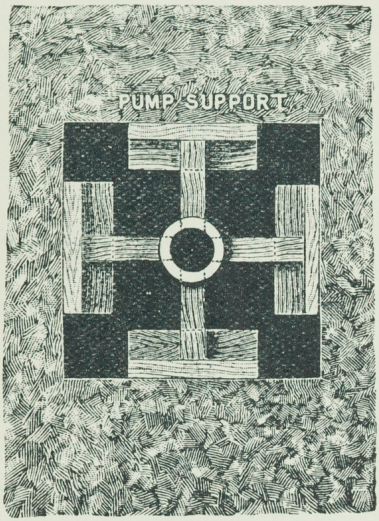

Fig. 16.—Top view of Pump Support referred to in Fig. 15.

Screen Points give better results where water is obtained from sand strata. One large screen point will give better results than a number of small ones. Where a large quantity of water is to be used, and the water-bearing stratum of sand is deep enough to permit of a greater length of screen point than is contained in one point, two or more, one above the other, should be used, unless the stratum is composed

of very coarse sand or gravel, and yields a large supply of water; but where the water-bearing stratum is not deep enough to permit such arrangement, two or more screen points may be arranged independently of each other (and far enough apart to prevent one from robbing the other), and then be connected to a suction pipe below the pump cylinder.

Screen Points should never be less than two-thirds the diameter of the cylinder. Those as large in diameter as the cylinder give better results. Their length will depend on the thickness of the water-bearing sand stratum. As a rule, the coarsest sand and gravel is found at the bottom of the stratum; therefore the screen point should be forced down to the very bottom. Everything else being equal, screen points of large diameter will supply water faster than smaller ones, and, when lodged at the bottom, in the coarsest sand and gravel, will supply much more water than when lodged higher up, where there is less gravel and the sand is fine. In river bottoms, where the strata are found to be 100 feet or more in thickness, it will be necessary to put a screen point down to the bottom of the stratum, but close attention must be given to the degree of coarseness of the sand or gravel in which the screen point is lodged. Under no circumstances should the point be lodged in anything but the coarsest sand or gravel. Points not less than 10 feet long should be used where there is enough coarse sand or gravel in the water-bearing sand to permit of doing so.

In every instance where a 10-ft. screen point is used, and there is enough water-bearing sand to permit it, the top of the point should be at least 15

feet below water level. In water-bearing sand strata which are too shallow—that is, too thin to admit of points 10 feet long being used—shorter ones should be used. In wells where the water-bearing stratum is only a few feet thick, the points must be only of such length as will ensure the top of the screen being entirely under water, so as to prevent air from finding its way into the pipe below the cylinder.

Well-making.—Open well-making, where open wells can be successfully used, is so generally understood that only wells where screen points are to be used will be considered in this connection.

To put down screen points, make an open well large enough to afford room for two men to work in, sink it down to water-bearing sand, and timber it to prevent caving in. After this is done, it is more satisfactory to bore down through the water-bearing stratum, so as to learn its thickness. A piece of gas-pipe, of sufficient inside diameter to admit the use of a common auger, may be used for casing, and, if made in 10-ft. lengths and properly threaded, may be put down in screwed lengths to the bottom of the sand. A common auger may be used to bore the sand out of the pipe by using an extension to the auger stem. The auger should be large enough in diameter to handle coarse gravel, and even pebbles. This will enable the operator to determine the thickness of water-bearing strata, and the location of the coarsest sand and gravel, as well as the length and diameter of screen point necessary, and the probable water supply that may be obtained from the well when finished.

How to Put Down Screen Points.—If the point to

be used is four inches, or larger, in diameter, remove the plug from lower end, and place it in the proper position, being most careful to keep it perfectly perpendicular, so that, when it is sent down to the finish, it will be perfectly plumb. When it is thus placed in position, use a sand bucket to remove sand from inside. As the sand is being removed from the inside, the point must be turned round and round, and, if this fails to lower it, it must be driven down as fast as the sand is taken out. When all the screen is down to the bottom of the open well, then connect a length of heavy pipe, for suction pipe, and continue to lower the screen point until it is down where it is intended to be lodged. As soon as the point is in position, then close up the lower end.

To Close Lower End of Screen Point, take enough Portland cement to form a plug as thick as equals one-half the diameter of the screen point. *Example:* For a screen point 10 inches in diameter, use enough to make 5 inches thick. To put cement in place, divide the quantity to be used into three equal parts; put each part into a separate paper bag, and tie a stout string or cord to top of one of the bags, and let it down gently to bottom of screen point; then, with a jerk, liberate the cement, and let down the remaining bags of cement in the same manner. The cement will set in the course of 48 hours.

RESERVOIRS, AND HOW TO BUILD AND MAINTAIN THEM.

Irrigation by windmills and pumps involves the selection of a good mill and a suitable pump or pumps, which supply the necessary machinery; but the irrigator must, in addition to this, build a suitable reservoir to store the water. The direct flow of water from the pump cannot be used in successful irrigation for two reasons—first, because of the absence of pressure required to push the water forward over the land; and, secondly, because the cold water drawn from the well is unsuited to plant life.

To Make a Reservoir.—First, select a suitable location, as high as, or higher than, every part of the land you wish to irrigate. Then lay off the lines marking the dimensions. If the land on which the reservoir is to be built be of fresh sod or soil, it will be necessary to plough up or remove all the soil from the ground on which the embankments are to be constructed; otherwise there would always remain a seam through which the water would escape from the reservoir. As sod is not fit material to use in the construction of embankments, it should not be used when building them up to their required heights. When the outlines of the embankments are established, and the sod removed, as before stated, then plough within the lines of the proposed embankments, and with a scraper draw the earth from the inside of the reservoir to build up the walls with. The walls should be not less than five feet in height (outside measurement), and very wide or thick at the ground level. They should be so carried up that the slope from the inside will be gradual, not abrupt, for, if the walls are nearly

perpendicular, waves will destroy them. The outer walls may be made more perpendicular, because there is no water from the outside to injure them. Having built the walls with earth from the inside of the reservoir, and everything ready for puddling the earth to hold water, the first thing is to plough up the whole bottom surface of the reservoir, four or five inches deep; then, with a harrow or drag, or other suitable implement, reduce the earth to a very fine pulverisation, and after this has been done, and thoroughly done, make ready to puddle.

Having your team, and that of your neighbour, if you can enlist his services, with drags, or harrows, or inverted scrapers, or other suitable tools adapted for working fine earth into mortar, turn the water into the reservoir, and begin to puddle at one edge; puddle carefully along this edge until the earth has been reduced by the combined action of the horses' feet and the working apparatus to perfect mortar, and continue to work along the other side until you have completed the entire bottom of the reservoir as far up on the embankment as you can work with your team to good advantage.

If you have done the work thoroughly, and without stopping after you have once commenced until it is all finished, your reservoir will cement into a good solid bottom that will hold water very well. The next thing is to provide means to prevent the embankments from being washed down by the continuous waves caused by the wind. Many different methods have been employed for this purpose. Some irrigators use sod for protecting the walls on the inside by laying the sodded blocks flat, in the same

manner now employed by landscape gardeners in sodding lawns and house-yards. If stone can be had, the better way will be to rip-rap the embankment with rubble stone on the inside, as it would be more permanent, and, as a rule, give more satisfaction. Some irrigators use planks thrown on to the water, which will float and be driven by the wind to the side opposite to that from which it blows,the planks acting as a breakwater to prevent the walls from being destroyed. When the wind changes, these boards blow over to the other side, and thus continue to protect the walls.

Another plan is to rip-rap the inside walls with brush and weight them with stone, or hold them down by staking. In this case, the twigs and limbs of small trees and bushes are laid down against the wall in a compact mass, as thick as the supply of the material will permit. This has been found to give very good results.

If the walls have been sodded inside, it will be well if some water grass can be procured from lagoons or water-holes, and planted in the seams between the blocks of sod; so that, by the time the sod rots out, the water grass may have taken root, so as to afford a living protection to the embankment.

The outside of the embankment may be sodded or planted with any suitable grass. To maintain your reservoir in good order, never allow it to go dry. If you do, the bottom will dry out and crack, and will require to be re-ploughed and re-puddled.

To get the water out on to the land is another matter. As we have located our reservoir on land of sufficient elevation, it will now only be necessary

to find a point of ground on the side which is the highest to locate our main ditch—*i.e.*, the start of the main ditch. The bottom of the main ditch should not be lower than the level of the ground; hence the ditch walls must be altogether a foot above the level of the ground. This keeps us above the level of the land we wish to irrigate.

How to Build a Water Box with Trap to carry the water from the reservoir to the ditch.— The box should be made of plank, two inches thick, and long enough to reach from the inner side of the embankment, through to the outer side, so that the bottom of the box will be no higher above the ground than the bottom of the ditch into which the water flows from the box. These boxes may be made in any width, such as 8 inches wide and 4 inches high, or 12 inches wide and 6 inches high, or 16 inches wide and 4 inches high, as may be most suitable. The capacity of the boxes should always be in proportion to the capacity of the reservoir. All the timber used in the boxes should be so long that the length of the board will be sufficient without splicing, and should never be less than 1½ inches thick. When the box is completed thus far, saw one end of the box off at an angle of about 45 degrees, in such a way that the longest part may be on the bottom and the short side on the top, and the widest part of the box should always lie on the ground, and not edgewise. To make a trap-door for this box, use a piece of timber wide enough and long enough to cover the end sawn off in the manner described above.

How it is Fastened to the Box.—Take leather, and make it in the form of a gasket, and fasten the leather

to the ends of the boards that you have sawn off, so that the lid or trap-door, which is to be hinged to the upper part of the box, will fall down over the end of the box and form a watertight joint. The weight of the water will cause the trap to remain closed; if not, a weight may be added. The trap end of the box must be on the inside of the reservoir, not on the outside.

The water lying in the bottom of the reservoir, below the land level, cannot be used. The first foot above the land level is of comparatively small value, because of the low pressure and the slowness with which it forces the water through the ditch. For these reasons the water should never be allowed to be drawn lower than a foot above the level of the outlet of the reservoir.

EVAPORATION.

The rapidity with which water is converted into vapour is dependent upon the relative temperatures of the water and atmosphere, and upon the amount of motion in the latter. Evaporation is greatest when the atmosphere is driest, when the water is warm, and a brisk wind is blowing. It is least when the atmosphere is moist, the air quiet, and the temperature of the water low. In summer the cool surfaces of deep waters condense moisture when they are supposed to be evaporating. When the reverse conditions exist in the atmosphere, and the winds are blowing briskly across the water, the resultant wave-motion increases the agitation of the body, and permits its vapours to escape freely into the large volumes of unsaturated

air which are rapidly presented to it in succession. Evaporation is constantly taking place at a rate due to the temperature of the surface, and condensation is likewise going on from the vapours existing in the atmosphere, the difference between the two being the rate of evaporation.

From the above it will be seen that evaporation should be greatest in amount in the arid regions of the West, and least in the ranges, its amount varying according to the altitude.

Observations made by Mr. H. C. Russell, late Government Astronomer, show the average monthly and yearly evaporation from water at the meteorological stations in New South Wales, as follows:—

	Bourke. 1885-1887 inclusive.	Hay. 1886-1895 inclusive.	Lake George. 1890-1895 inclusive.
	Inches.	Inches.	Inches.
January ...	8.892	6.237	4.084
February ...	7.177	4.820	3.115
March ...	6.658	4.212	2.607
April ...	5.294	2.708	1.821
May ...	2.832	1.462	1.175
June ...	1.981	1.322	0.908
July ...	1.875	1.140	0.744
August ...	2.485	1.663	1.125
September ...	3.729	2.422	1.803
October ...	5.834	3.784	2.963
November ...	8.168	4.806	3.496
December ...	8.361	5.807	4.234
Total ...	63.286	40.383	28.075

	Summer. Greatest in any one day. Inches.	Winter. Greatest in any one day. Inches.	Greatest in a month. Inches.
Bourke, 1887 ...	0.626	0.165	8.791
Hay, 1895 ...	0.300	0.071	6.013
Lake George, 1895	0.332	0.062	5.649

Evaporation from Earth.—The amount of the evaporation from earth in the western districts of Australia is a doubtful quantity. The most important experiments bearing on earth evaporation were made in England between 1844 and 1875. The evaporation from sandy surfaces was found to be only one-fifth that from water. Thus, in the observations of 1873, where the mean evaporation from water was 20.4 inches, that from sand was 3.7 inches. Soil cover of any kind greatly affects the amount of evaporation. Assuming the evaporation as 1.00, Prof. B. E. Fernow gives it for bare soil 0.60, sod 1.92, cereals 1.73, and forest 1.51. Evaporation from ground covered with forest leaves is 10 to 15 per cent., and from sand 33 per cent., of that from bare ground.

As this loss of water through evaporation in a hot climate like Australia is a matter of considerable moment, any mode or device for reducing or neutralising it is of considerable importance. If a plate and a bottle be filled with the same quantity of water and placed in the sun, the water in the plate will dry up the quicker. On the same rule, dams and reservoirs should be made with a small surface area and as deep as possible, with the object of preventing the water from becoming hot, and presenting the least surface for evaporation.

To ascertain if floating water weeds retard evaporation, as had been alleged, observations and experiments have been made. Fresh-water plants, with a few exceptions, will not grow in water deeper than five feet. Some few grow in ten feet, and, under very favourable conditions, in deeper water; but

fifteen feet may be taken as the absolute limit that any fresh-water plant, rooting at the bottom, will grow. These large water-lilies require shallow water wherein to establish themselves, and to extend gradually to deep water. It would be hard to start them in deep water at first. Reservoirs and permanent waterholes are seldom less than ten feet deep—generally more—so that it would be impracticable, even if it were desirable, to cultivate water vegetation in them. A number of glass cells, each of the capacity of one gallon of water, were arranged, some with and some without water weeds. One series was placed outside in the sun, another series in the shade and under cover. Duckweed and the blue water-lily were the plants used. From these experiments it was seen that evaporation was neither retarded nor hastened. The only practical remedy appears to be oil, which, in a slight film or quantity floating on the surface, almost entirely prevented evaporation. Under the heading "Treatment of Alkaline Lands," page 198, it will be seen that tilth in cultivation also reduces evaporation upon irrigated land considerably.

DITCH-MAKING.

The Main Ditch.—It should be made on a higher level than that of the land to be irrigated, so as to command a flow into the laterals or small ditches, the bottom of which should be level with, or above, the surface of the ground, so as to utilise all the water in the ditches. The water for irrigation being ready for use, small distributing ditches must be made by ploughing out a ditch and throwing up parallel banks

of earth. A section of such a ditch is shown in Fig. 17. Fig. 18 shows a raised ditch to carry the water over a hollow portion of the paddock whenever such

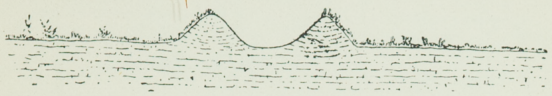

Fig. 17.—Section of small Distributing Ditch.

is met with. A plough and scraper are used in the construction of the ditch, and the earth is thoroughly packed to prevent settlement when the water is let in.

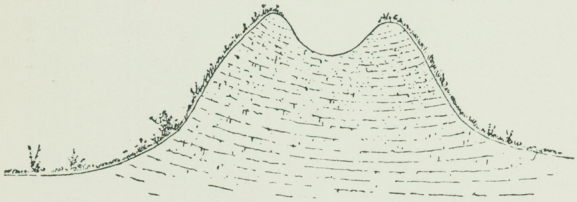

Fig. 18.—Section of small Raised Ditch.

Fig. 19 shows sections and elevations of small timber flumes, which are necessary in order to carry the water over deep hollows in place of a raised earth

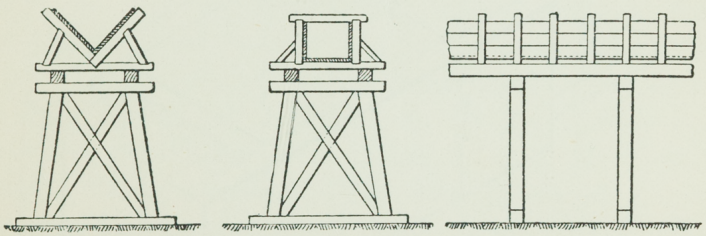

Fig. 19.—Sections and Elevations of Small Flumes.

ditch, which would be liable to be washed away by floods. There is a saving of timber in the V-shaped flume, but the rectangular one is more generally used.

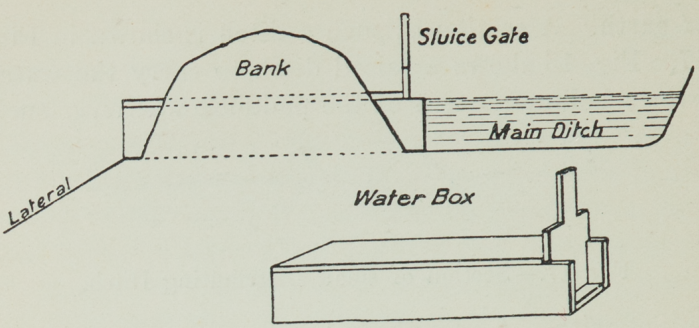

Fig. 20.—Box for taking Water from Main Ditch.

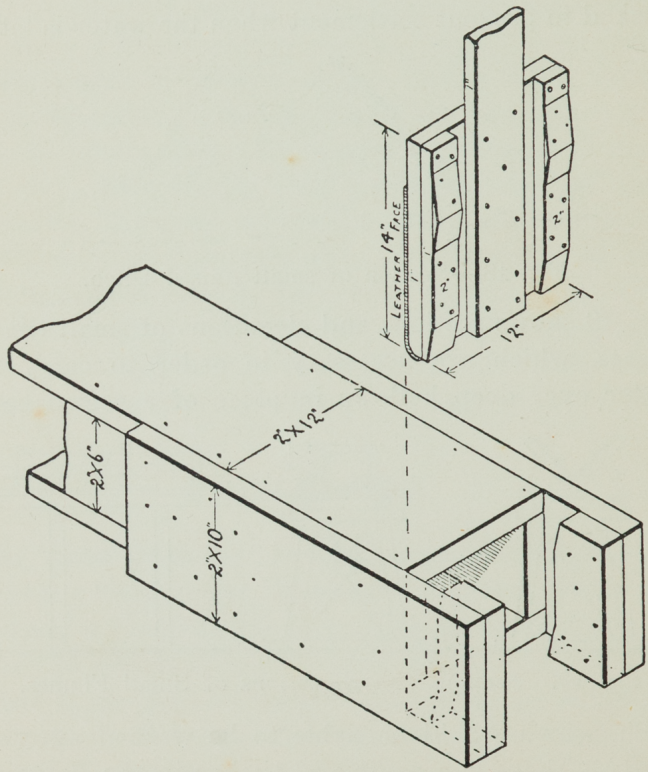

Fig. 21.—Details of construction of Box for Distributing Water.

In order to pass the water from the main ditch into the smaller ones, or from one lateral to another, small wooden boxes, or gates, are used. This is preferable to simply cutting an opening in the ditch bank and filling it up again when enough water has been let through, because leakage may occur, and the water scour out a large hole before the bank can be closed up again. Figs. 20 and 21 show a simple form of box made of planks, with a sliding gate at the up-stream end. If these boxes are carefully bedded in clay, leakage from outside will be prevented; and, if the sliding-gate facings are made smooth, they will be rendered nearly watertight, or a leather facing may be used with a still better result.

PREPARING LAND FOR IRRIGATION, PLOTTING INTO FIELDS, AND SUBDIVIDING INTO BEDS.

To Put Land in Shape to Irrigate.—Plough the land as deep as convenient. Then make a drag in the form of a letter A, with base 8 feet wide and top 16 inches wide, constructed with plank 2 by 6 inches and 12 feet long for side pieces, and suitable planks for cross pieces, to bind the outside pieces firmly together. The side pieces should be arranged on edge. When ready to go to work, hitch to wide end of the frame, and, after you have decided how wide and long to make the beds, drive straight across the field from one side to the other. The wide-spreading ends of the drag gather in the loose earth,

clods and all, and heap it up behind. This forms ridges separating the fields into beds. The width of these beds will depend largely on the size of the reservoir. If the land is so large that it will require more water than the reservoir contains at one time, it will not be all properly irrigated.

After the field has been laid off into beds as described, a scraper will be useful (Fig. 22), if the ground between the ridges is humpy or uneven. The humps should be scraped into the low places, and

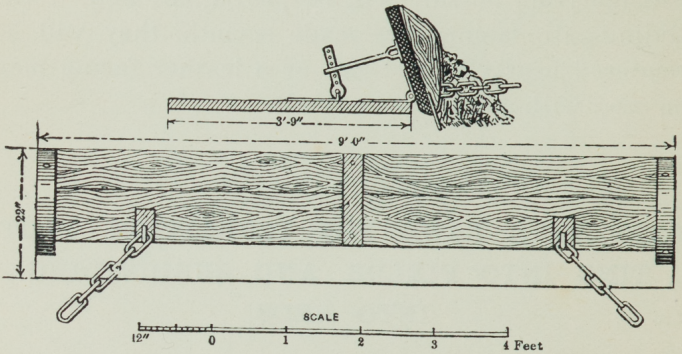

Fig. 22.—Buck Scraper.

after this is done a harrow or drag should be used. To finish up with, a board leveller, well weighted down, should be dragged over the land to put the beds in perfect condition, so that the water will spread evenly and flow rapidly over the ground so as to cover the entire bed. The ends of the bed should come up to the main ditch, or a lateral ditch, so that the water can be turned in full volume out of ditch on to the end of the bed. To do this, construct a dam about opposite the ridge which separates the bed to be

watered from the next bed below it, and then cut the lower side of the wall of the ditch about the middle of the bed to be watered, and allow the full volume of the water in the ditch to flow out on to the end of this bed. The bottom of the ditch, as before said, should be above the level of the ground composing the bed.

The length of the beds will depend entirely on the lay of the ground and kind of soil. If comparatively level, but sloping gently, 10 to 40 rods is a good length. The height of water in the reservoir above ground level, kind of soil, and slope of the land all have certain effects, and no general rule will fit every case. It may be well to make short beds, under one condition, while in certain cases beds may be made 80 rods long.

Watering the Crops.—Potatoes, as well as sweet potatoes and maize, should be watered between the rows. To do this, a furrow should be run between the rows, beginning at the end of the land by the ditch, and only water enough turned on from the ditch to fill up the furrows.

Vegetables, and all crops that are started by level cultivation (except field crops, such as wheat, barley, rye, oats, and grasses) should be watered in small areas, or over shorter distances, to avoid over, or else insufficient, watering. As soon as vegetables can be cultivated in rows, then the water should be confined to the space between the rows when irrigating.

To Turn the water on.—Arrange the dam in the main ditch just below the point at which you wish to turn the water into the lateral. The usual method is to construct a box with a trap in main ditch, just

below the juncture of the lateral with the main ditch, and also have the same kind of dam across the lateral a few feet from the junction, so that the main ditch may be closed and the lateral opened, or vice versa. Then put in the dam across the lateral close by the ridge separating the land below from the one you wish to irrigate, and cut the embankment at the lateral on the side next to the land to be irrigated. Then open the water-box of the reservoir by lifting the trap-door just enough to allow as much water as you can use, without waste, to flow out into the main ditch. The water will flow rapidly along the main ditch until it reaches the lateral, and will then follow it out and over the bed. The evenness of the flow over the bed will determine how well you have done your levelling of the land.

If your reservoir supplies water enough for two or more beds at one time, irrigate only one bed at a time, and as soon as you have finished one bed, remove the dam which closes your ditch, and move along to the next ridge, and put in a new dam there; cut another opening through the lower side of the ditch embankment, closing up the opening first made, and thus turn water off from the bed just irrigated, and on to the fresh bed to be watered. Continue in this manner as long as the reservoir holds out.

The best results are obtained in the late evening, thus giving the water time to soak into the ground before the sun scalds the plants.

Canvas Dams.—How to Make a Canvas Dam:—First measure the main ditch across the top of the embankments for the length of scantling necessary

to reach across. The scantling should be 4 by 4 in. timber; then take ducking cloth (old grain bags will do, by ripping them), a yard or so wide, and fasten one edge of it to the scantling with carpet tacks or by nails.

How to Use it.—Place the bar of canvas dam across the embankment of the ditch where needed, and take hold of the lower or loose side of the canvas, and spread it across the ditch up stream. Then with a shovel throw a small amount of earth on the loose edges to hold it down; and, if you have had no previous experience, you will be surprised at the satisfactory result obtained with this dam. Its chief advantage is the ease and quickness with which it may be changed from one place to another. It is a very portable dam.

Sloping Land.—How to lay off Ground for Irrigating when the land is too sloping to allow the Water to run straight down the Slope:—In all land which slopes at a sharp angle, it will be best to so arrange the beds that the water will flow across the slope instead of down it. In this case, the ditches must all be properly located, and the beds worked down to as perfect a level as possible; at the same time, there should always be a gentle slope to the beds, beginning at the ditch end and continuing through to the other end. This is obviously needed in order that the water may flow readily the full length of the bed.

Uniform Spread of Water over the entire bed is the most desirable object. To effect this, you must have the necessary supply of water—a full reservoir, to begin with, and your beds in good shape, with both

main and lateral ditches properly made and in good order, with a sufficient flow of water out of reservoir into ditch. It is the pressure of water in the reservoir that pushes the water ahead, and causes it to spread over all kinds of soils before it can soak away in the ground. For this reason, the last half of the water in the reservoir is not as valuable as the first or upper half.

General, as well as Special, Crops, should be Grown.—To obtain the fullest results from irrigation, such a full line of crops should be grown as will permit of all-the-year-round work. Wheat, rye, and lucerne will require irrigation in the autumn and winter; orchards also require watering in the winter. Lands intended for spring crops should be thoroughly watered in the winter; all kinds of spring crops, including maize and vegetables, require watering in the spring. Most vegetable crops require watering in summer; also, the orchards should be watered for the last time in mid-summer. It is by general crop-culture that irrigation with pumping power is to be made most profitable.

Flooding-in Checks.—In imitation of Nature, when a river overflows its banks and irrigates the surrounding country, rendering it extremely fertile, checks, or slight embankments, are made of a rectangular form, dividing the paddock into compartments, as shown in Figs. 23 and 24. If the land is at all sloping, the water is let into the upper section first, and, after that has been flooded, an opening is made in the bank at the lower side, and the next section is flooded, and so on until the whole are watered.

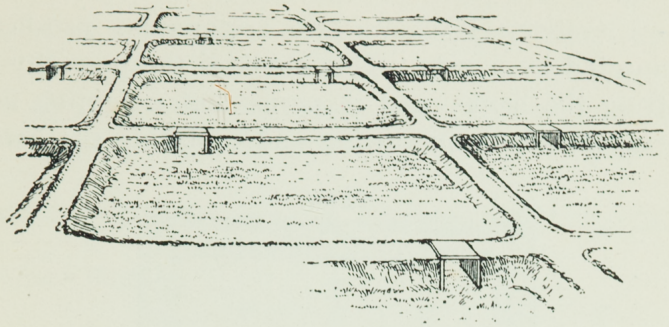

Fig. 23.—Portion of Paddock divided by rectangular checks.

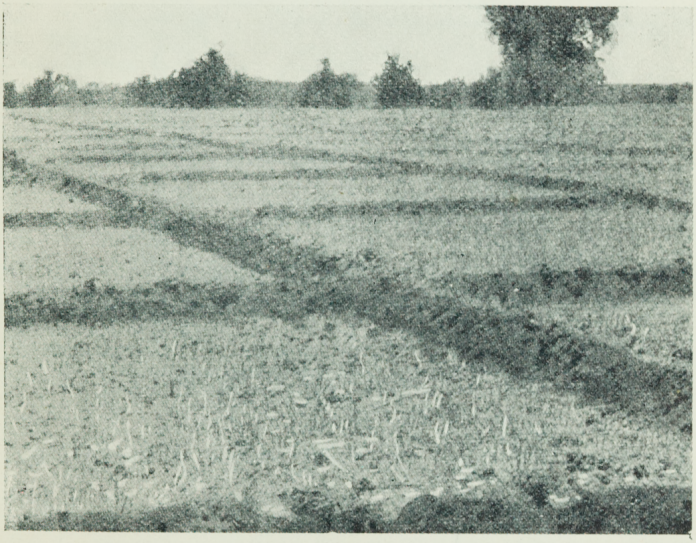

Fig. 24.—Paddock prepared in rectangular checks.

Fig. 25 illustrates an application of water by the block system. It shows two rectangular paddocks connected by a gate. This obviates the necessity of cutting the banks, and in permanent irrigation is a saving in labour in cutting and replacing the bank.

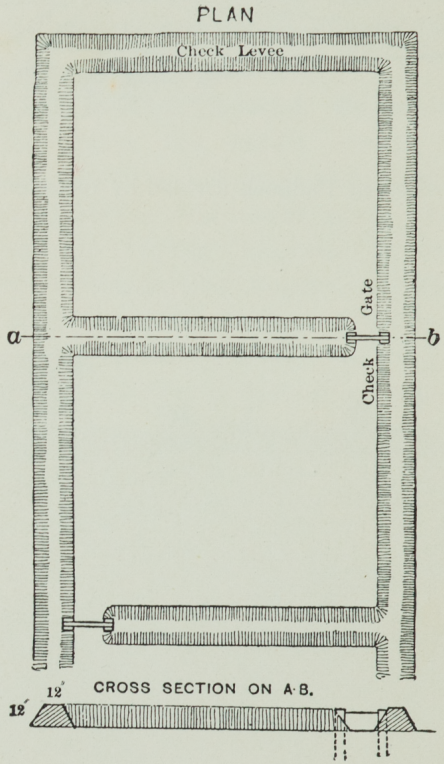

Fig. 25.—Application of Water by the Block System.

The usual size of the paddock is 20 to 60 feet in length, and the ridges are 10 inches in height.

Fig. 26 illustrates flooding in rectangular checks of paddocks up to 20 acres or more. The ground is

first levelled and then divided by checks from one to two feet in height and five to ten feet in width. Water from the supply ditch is let into the first section (1) through a gate-opening, and, when that section has been watered, the lower side is opened and the next

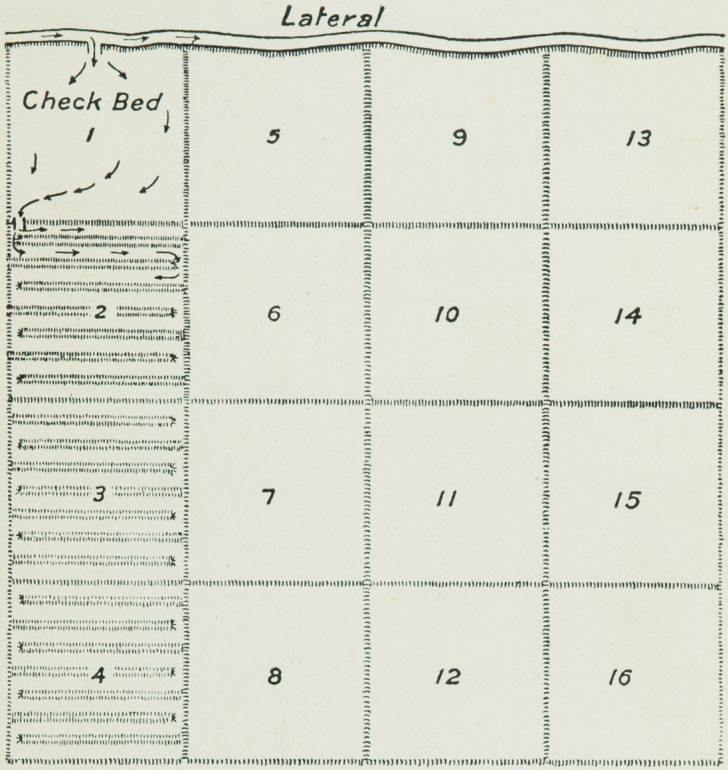

Fig. 26.—Flooding in rectangular checks.

section (2) is watered, and so on to No. 4. The same process is then followed with sections 5 to 16, or the whole of the sections may be watered at the same time

An alternative mode, by which more uniformity is assured, is to let the water flow until the lowest sec-

tions are covered to a depth of about three inches; then close the opening, and allow the water to cover the next section above, and so on to Nos. 5, 9, and 13.

For the cultivation of garden crops, ridges are made

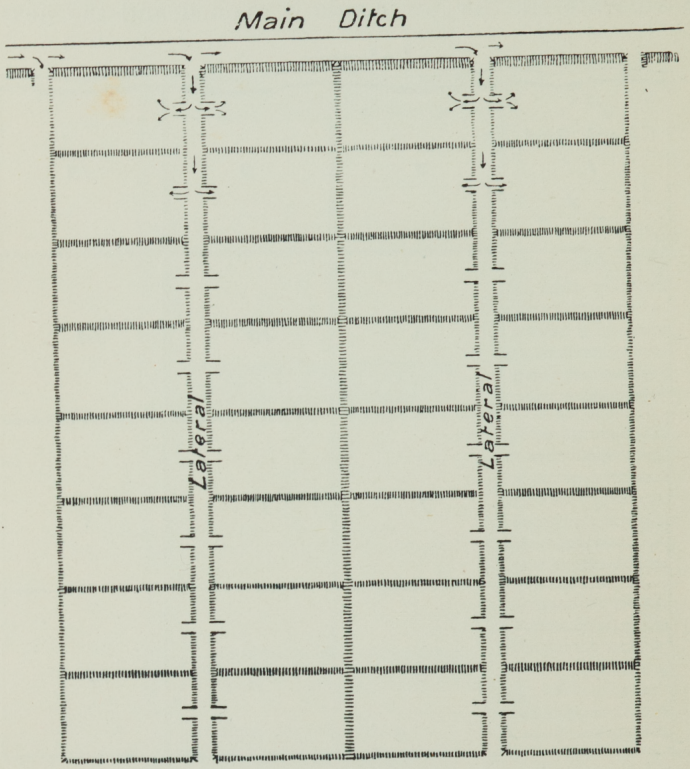

Fig. 27.—Plan of Irrigated Garden, divided into compartments or checks.

as shown in sections 2, 3, and 4, the water being made to flow around, and nearly to the top of, the ridges. Chinese gardeners adopt this mode.

Lateral ditches may be made as shown in Fig. 27 by which the water can pass directly into any section.

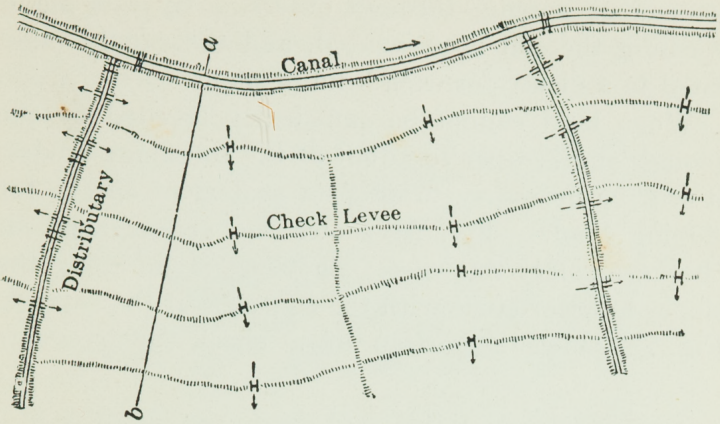

Fig. 28.—Checks on Sloping Land.

Fig. 29.—Irrigation by Checks in San Joaquin Valley, California.

instead of passing through others. By this mode washing the soil is prevented, and the supply regulated to a nicety for each kind of plant.

When land cannot be sufficiently levelled by the plough and scraper to admit of the foregoing modes, it will be necessary to adopt a system of checks for sloping land. Fig. 28 shows the arrangement of checks to meet this case. They are made along the slopes in accordance with the contours of the surface. Fig. 29 shows a portion of a check on irregular

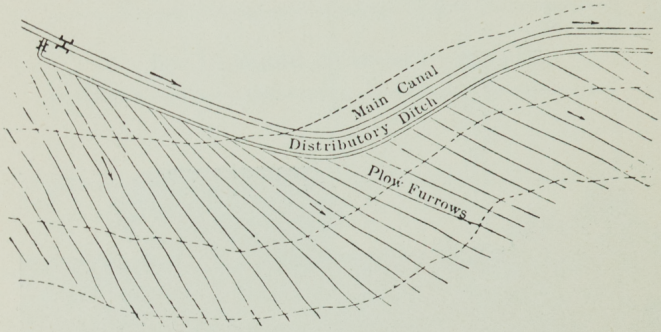

Fig. 30.—Furrow Irrigation of Grain.

ground. A series of banks, a foot or two in height, are made, approximately parallel to the line of the supply ditch, and may be 80 to 100 feet or more from it, dependent upon the slope of the surface. These form successive sections, and are supplied with water by distributing ditches as shown in diagram.

Furrow-Watering.—The mode shown in Fig. 30 is particularly applicable to crops which are grown in furrows, such as maize and potatoes, and takes the place of the more expensive mode of levelling and banking the ground. The ploughing may be so di-

rected that a minimum amount of water will pass freely without disturbing the soil. The illustration shows furrows ploughed diagonally across sloping

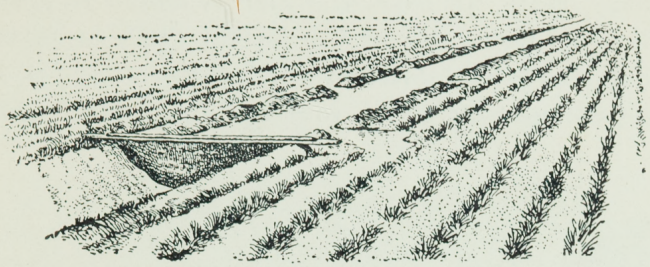

Fig. 31.—Water turned from furrow by Canvas Dam.

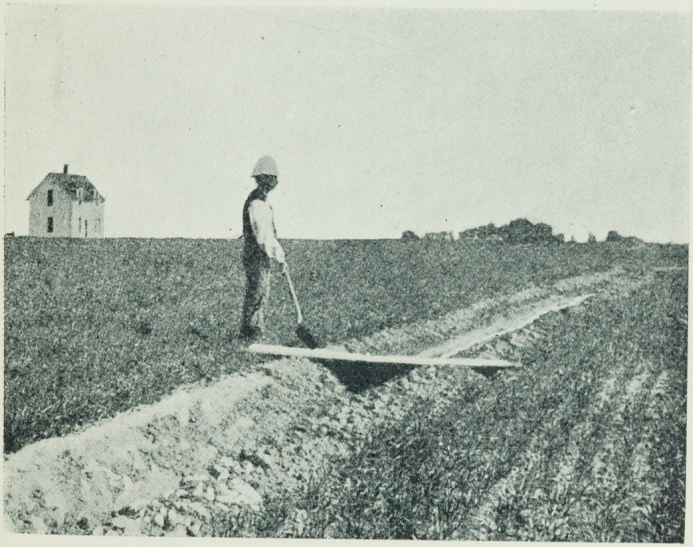

Fig. 32.—Canvas Dam in Temporary Ditch.

land, thus reducing the velocity of flow of the water. Too steep a fall does not admit of time for the soil to absorb sufficient water.

Water is diverted from the ditches by using temporary dams of earth, canvas, sheet-iron, or boards. A canvas dam, as shown in Fig. 34, is made of strong "duck" cloth, an edge of which is nailed to a stick as long as the width of the lateral ditch or furrow. The canvas is held down by earth thrown upon it, and the accumulating water forces it into place. After

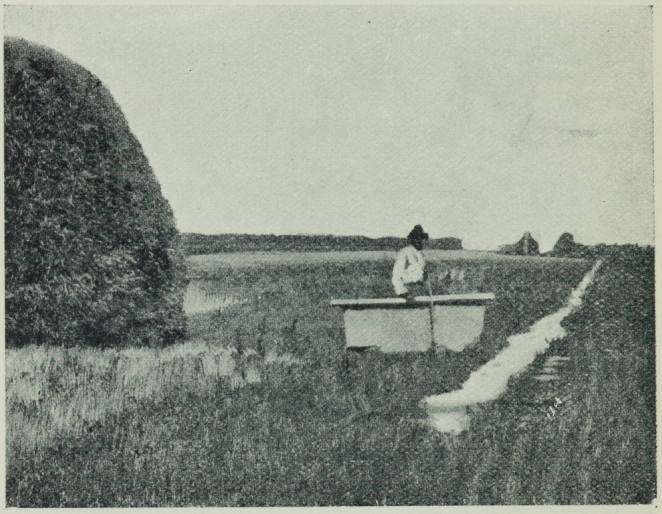

Fig. 33.—Irrigating a young Lucerne Paddock.

the watering of one section is completed, the dam is pulled up and used for the next section.

Figs. 35 and 36 show forms of iron and wooden tappoons, the oval shape fitting the furrows. The left-hand drawing has a pin which projects below the bottom of the tappoon, holding it in place. Holes may be bored in the tappoon, and any desired flow obtained, the holes being plugged when not in use.

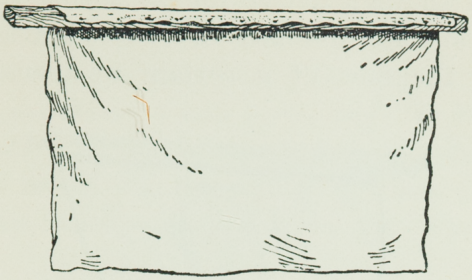

Fig. 34.—Canvas Dam.

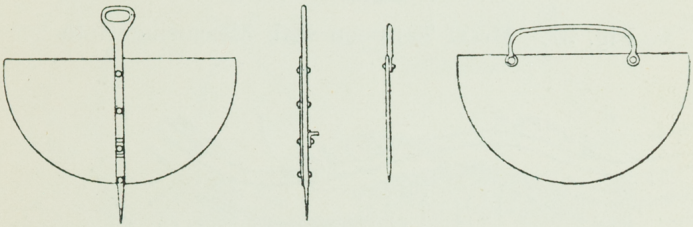

Fig. 35.—Metal Tappoons.

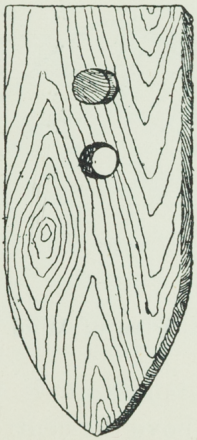

Fig. 36.—Wooden Tappoon provided with Outlets.

Fig. 37 shows a device for measuring roughly the quantity of water discharged. There is a sliding door allowing the flow of a certain number of square

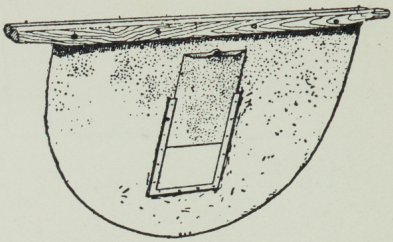

Fig. 37.—Metal Tappoon with Measuring Gate.

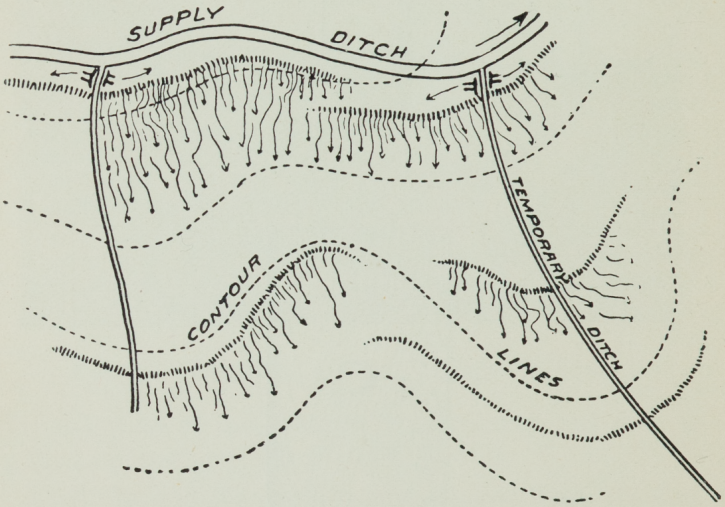

Fig. 38.—Plan of Wild Flooding.

inches. When the pressure is maintained at from four to six inches above the centre of the opening, the delivery can be computed in miners' inches.

Wild Flooding.—As checks or furrow-watering will not apply to grass land, lucerne, etc., it is necessary to provide what is called wild-flooding for them. It requires considerable care to do this. In Fig. 38 the dotted lines show the contours of the ground, or lines of equal elevation. Across these lines temporary ditches are made, leading from the supply ditch,

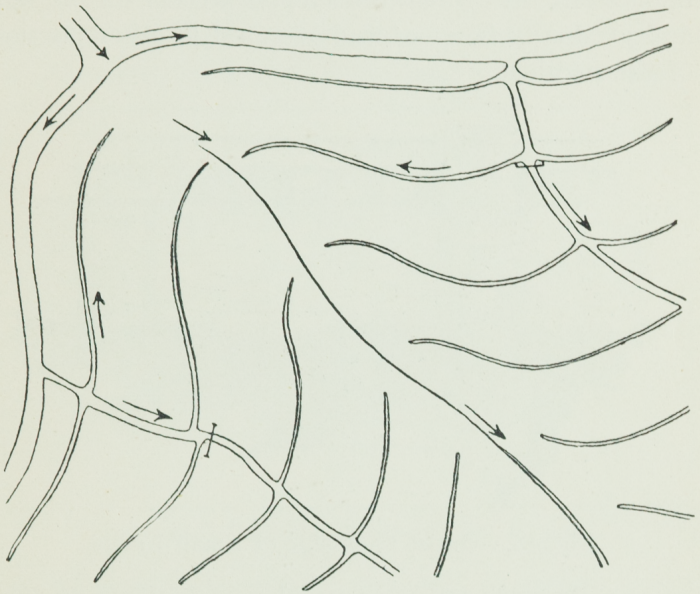

Fig. 39.—Plan of Distributing Water on Rolling Lands.

which is made to follow one of these contour lines. On each side of the temporary ditches, slight elevations, acting as checks, are made, which throw the water out along the line of the contours and spread it over the land, as shown by the irregular lines on the figure.

If the land is undulating, water is run out upon the

smaller ridges, thoroughly wetting the surface before it escapes into the depression. This system is shown in Fig. 39, in which the temporary ditch takes a line of fall in two directions. Laterals are made from this ditch, the arrows showing the direction of streams of water, gradually vanishing into the grass lands or cultivations. The line in the centre shows a line of depression, into which the surplus stream waters flow, and gradually flow out and are used in other portions of the paddock.

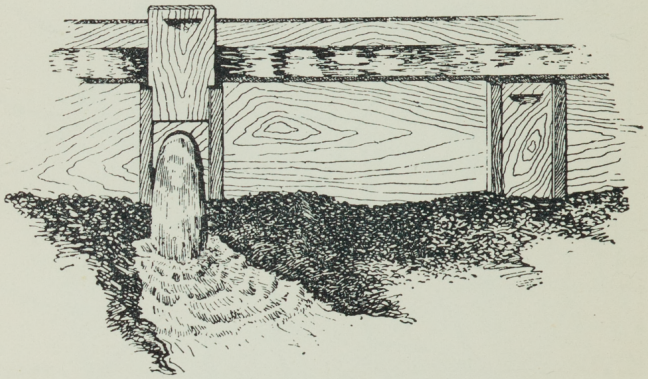

Fig. 40.—Outlet from side of Small Flume.

Orchards and Vineyards.—The necessary supply is often brought in wooden flumes as near as possible to the orchard or vineyard, and is then run into the furrows between the trees. Fig. 40 shows one of the small flumes (see also Fig. 19) and distributing boxes. The latter are placed from three to five or more feet apart, and a number of them are in operation at the same time, each delivering the water into a furrow.

Where economy in the use of water is an abso-

lute necessity, a method is practised of irrigating trees in basins, as shown in Fig. 41. A bank is raised around the trees, with an interior bank enclosing each tree. The objection raised to this method is that of the tendency of the roots to develop near the surface. As the elevated portions of a valley are, on account of a higher and more favourable temperature, preferable to the bottom lands, and as the soil of the slopes is mostly of a high quality, orchards have been formed on hill-sides, and irrigation laid out accordingly

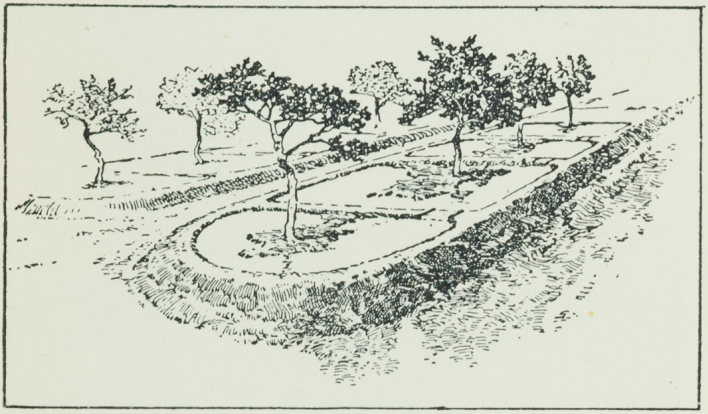

Fig. 41.—Orchard Irrigation by Pools.

Fig. 42 shows a successful method. A stream is conducted down a slope by means of a wooden flume made in horizontal sections, one lower than the other, following the fall of the ground. The water flows through small outlets in the flume into the furrows.

Figs. 43 and 44 show furrow-irrigation of vines and orchards. These views show a very liberal use of water, which is only possible where the supply is a large one. If the supply be limited, it pays better to store it in small reservoirs and let out a large

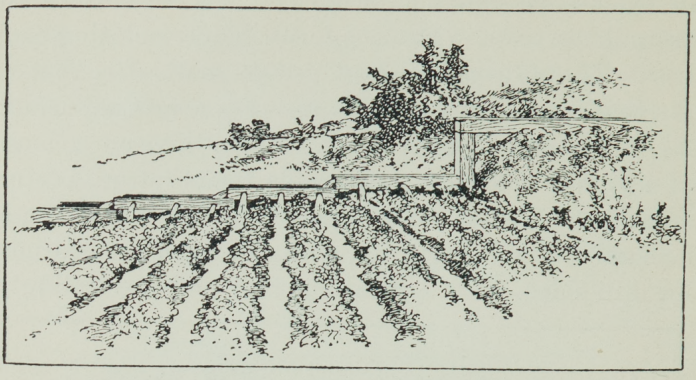

Fig. 42.—Irrigation on Slope with Stepped Flume.

Fig. 43.—Furrow Irrigation of Vines.

volume at once. By this means the ground receives a thorough wetting, with more uniformity to all parts of the orchard. The direction of the water is regulated by the irrigator, who with a long-handled shovel keeps the furrows open, or closes them by throwing in earth, care being taken that the water does not accumulate in depressions.

Fig. 44.—Furrow Irrigation of Orchard.

Where permanence and economy of water have to be studied, the system shown in Fig. 45 is adopted. Cement is used in the construction of the distributing ditch, which is provided with drops and gates, by means of which the water is raised and forced to flow out through small openings in the sides.

Fig. 46 shows furrow-irrigation of a mature orchard; and Fig. 47 shows proper cultivation, or tilth, of the land after irrigation.

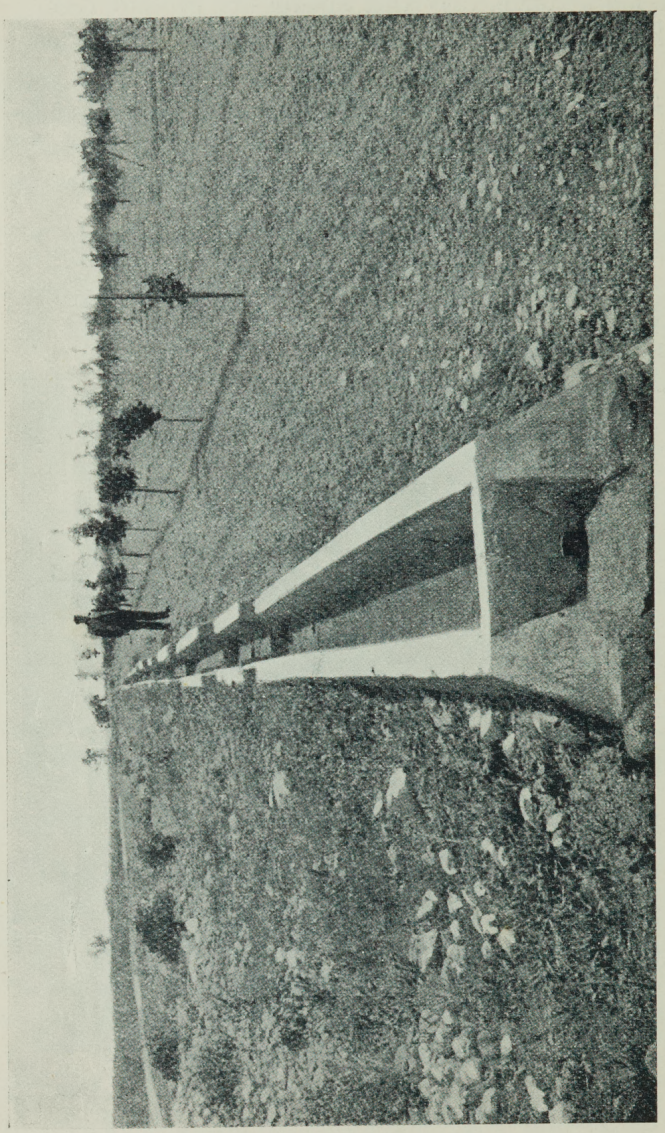

Fig. 45.—Cement-lined Distributing Ditch.

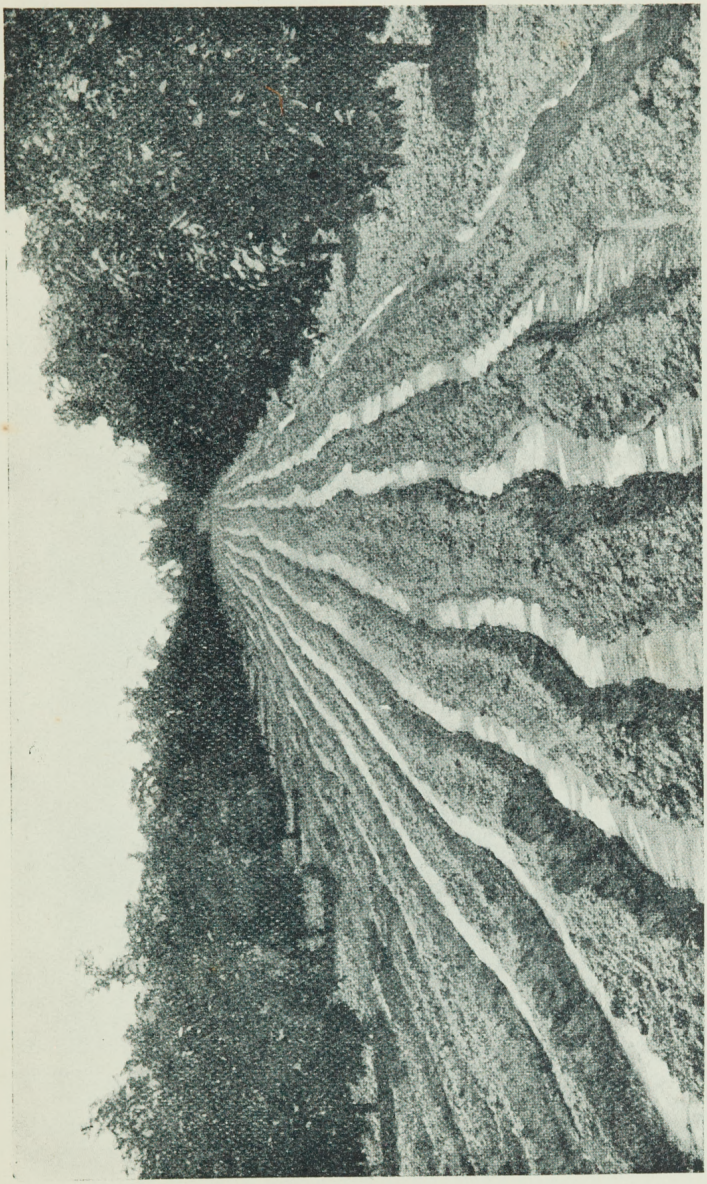

Fig. 46.—Furrow Irrigation of Orchard.

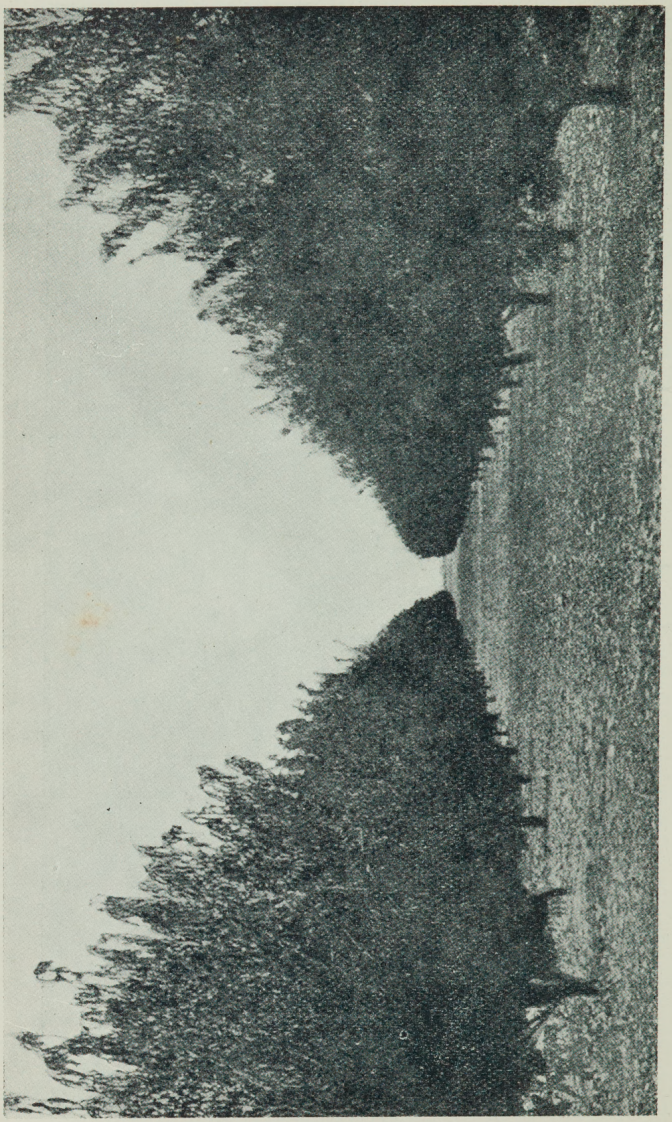

Fig. 47.—Cultivation after Irrigation.

When and How to Water the Land and Crops.—The very first duty of the irrigator who has his land in proper shape for irrigation, is to turn the water on in sufficient volume to thoroughly wet the ground, including the sub-soil. Air is as important, and as necessary for plant life and vigour as it is for animal life. Therefore, every effort must be made to retain this air in the soil. A flood of water drives the air out; but if the water be allowed to soak away into the soil, and the soil be allowed to assume a normal condition before being stirred, the air will follow the receding water, and again take its place. In good time, before ploughing in the spring, water the ground thoroughly. When it is in good working condition, plough carefully; then, as soon as possible, harrow, or otherwise pulverise the soil very fine. *Cultivation, careful cultivation, intense cultivation*, is more important from now on, until the crop is harvested, than water. Do not depend on water alone, but depend more on careful and intense cultivation to produce big crop yields. Many irrigators, just undertaking farming by irrigation, are liable to drown the crops; they will also waste the water by putting too much on the ground, during the growing season, by watering too much at a time and too often.

Attention has already been called to the evil of driving the air out of the soil by flooding with water. There is another way of driving out the life-giving air, without drowning it out, and that is to work the ground when it is too wet. Stirring wet soil kneads it into compact masses, driving the air out of the interstices, which should always remain between the earth particles. This produces a "puddled" or

"baked" condition. For the same reason, as soon after watering the growing crops that require cultivation as the soil is in proper condition to work, a suitable implement should be used to pulverise the surface over which the water flowed, which will again permit the air to enter the soil. In all crops requiring cultivation the surface of the soil cannot be kept too finely pulverised.

Corn-Maize.—If the irrigator has complied with the foregoing, let him plant the maize and cultivate it carefully, and there will, probably, not be required any further irrigation until the stalks begin to tassel —when, if the cultivation has been done by what is known as the "level" system, let him run a furrow with a large shovel-plough midway between the rows, for the water to flow down through. When irrigating, the water must be confined to the furrows, so that it may not spread over the ground about the roots of the stalks. If it does injury will be done through baking, since it will be quite impossible to break up the baked crust about the roots of the growing plants. The water soaking into the ground from the furrow spreads through the soil to the maize rows on each side of the furrow. As soon after watering as the soil is in proper condition, a suitable implement should be used to gather the soil back into the furrow, at the same time disturbing the corn roots as little as possible. One more watering will be ample, and should be done about the time the maize is in " good roasting ear," filling up the furrows as before.

Sorghum and other kindred crops should be watered in a similar manner to maize.

Potatoes should be watered in the same manner as maize. The best results are obtained by "hilling" the potatoes—that is, by throwing the dirt to the rows of potatoes with a plough; this leaves a deep furrow between the rows. No water is to be used until the young tubers have set. If watered immediately before setting, a greater number of potatoes will be formed than the plant can support, and consequently but few of them will grow large enough for the market. When the tubers have set, turn the water into the furrows, being careful not to make them too full; otherwise, should the water flow over the hill and against the vines or plants, the soil will "bake" and the water will "scald" the plants. When once irrigation has commenced, the water must be turned into the furrows every eight or nine days, until the tubers have developed to the size desired, when the watering is to be discontinued and the soil allowed to dry out, so as to ripen the potatoes in good form. After every watering, as soon as the soil is in proper condition, a suitable tool should be employed, and drawn by a horse, to break up the crust that otherwise would form in the furrow through which the water flowed.

Root Crops, such as turnips, beets, carrots, etc., may be watered at any time after planting, provided care is taken to keep the soil in a mellow condition.

Fruits should be thoroughly irrigated in the autumn as soon as the leaves are brown, or fall off, and again in the spring. The orchard should always be cultivated and kept free from weeds. Until the trees shade all the ground, more or less, crops that require cultivation may be grown among the trees. The

cultivation of fruit trees should be merely surface deep, so as not to disturb the rootlets which seek the very top of the soil for sunshine and air, to support and mature the fruit. Too much water is as injurious as too little for fruit trees, as for other crops. Orchards should never be irrigated until the leaves fall off in the autumn.

Wheat and Rye.—The land to be sown to winter wheat and rye should be watered with a flooding equal to five inches of water before ploughing the ground preparatory to seeding. As soon thereafter as the ground is in order, plough, and follow the plough with a harrow or other suitable implement, to pulverise the clods; and an excellent plan will be to follow the harrow with a land roller. The ground will now be in an excellent condition to seed, which should be done with a drill. No more water is required until just before winter, when a flooding equal to three or four inches of water should be given. Again in the spring give another three or four inches. Once more only, and that just when the first indication of heading is seen, give the last flooding of three inches, which completes the wheat and rye irrigation.

Spring Wheat, Spring Barley, and Oats.—Follow the same plan as for maize. Prepare the land and seed in proper season. The first watering after planting should never be done until the young plants are of sufficient growth to shade the ground. Then apply three or four inches of water. Spring wheat and barley, like winter wheat and rye, must not be irrigated after heading.

Oats are the exception, and should be irrigated once after heading, when filling, to ensure the best yield.

Pastures should be irrigated in the autumn, before the cold weather sets in, by flooding with four or five inches of water, and again in the spring at the beginning of the growing season; they should be watered from time to time during the balance of the season, about once every three or four weeks, with three or four inches of water each time. Pastures intended for hay should not be irrigated less than two weeks before harvesting.

Lucerne, when intended to be grown for seed, should be irrigated just as other clovers, once after the cold weather in the spring, when four or five inches of water should be used. Then no more irrigation should be given until the seed crop is harvested. As soon as possible after harvesting either a seed crop or a hay crop of lucerne, the fresh stubble should be irrigated with four or five inches of water. As a rule, one irrigation is sufficient to mature either a hay crop or seed crop of lucerne.

In Conclusion, it must be borne in mind that the rainfall in the growing season should be taken into account. Since it is only necessary to supply the land with 24 inches of water during the twelve months, no more water should be used in irrigation than is necessary to make up the deficiency of the rainfall to complete the 24 inches. *Too much water is always injurious, instead of beneficial.*

ARRANGEMENT OF IRRIGATED FARM.

Fig. 48 shows a farm with a variety of crops, and orchard and garden under irrigation. On the top right-hand corner is the highest portion of the land

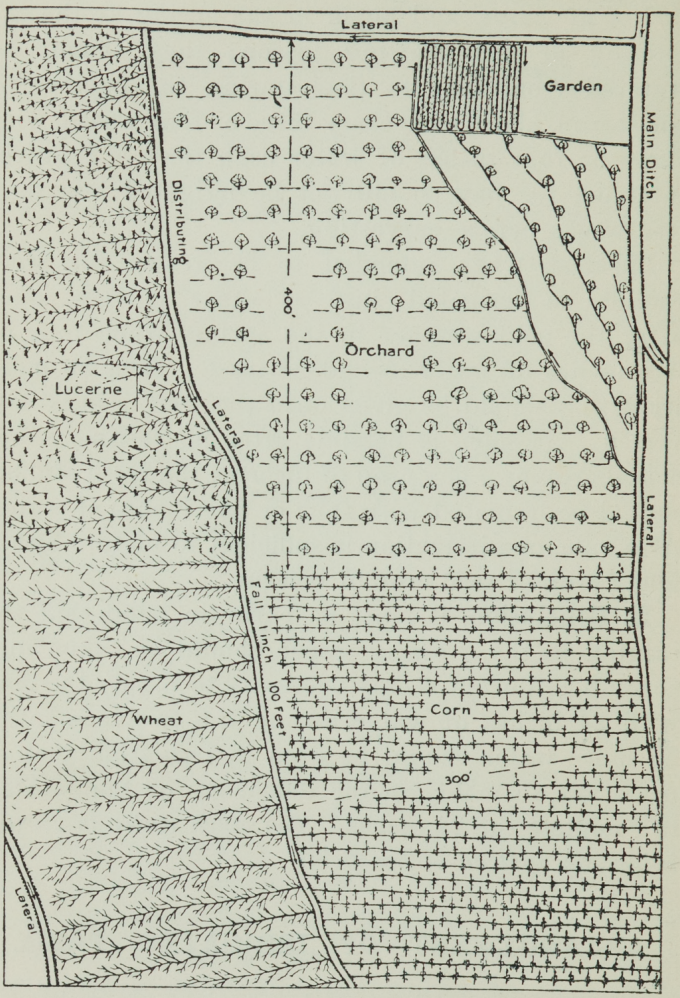

Fig. 48.—Plan of an Irrigated Farm.

and on this are the house and garden, the latter being cultivated in furrows. On this higher land the main ditch is shown. Next to, and below this, the orchard is shown, so laid out that the water flows along the trees, which are planted on contour lines on the slightly sloping ground. Below this, as the surface is nearly level, the trees are set out in straight lines. Next to the orchard there is a crop of maize irrigated in rows. A distributing lateral, running irregularly from the main ditch, supplies water to the lucerne and wheat, both of which are watered by flooding. The lateral shown in the left-hand lower corner receives any excess of water, passing it on to other paddocks. Fig. 49 shows a main canal running across the farm. Lateral ditches from the main ditch are run along two sides of the farm, as indicated by the contour lines. From these ditches distributing ditches flow inwards towards the main canal, generally following the contour lines. Around a depression run two forked ditches, so that water can flow on both sides into the depression. After commencing and continuing irrigation, the water level on the farm and vicinity is gradually raised, so that the quantity of water needed annually decreases. It has been found that the ground water, which was previously from 15 to 18 feet, is now 10 to 12 feet only beneath the surface, as shown by test wells. The figure also shows that, during the irrigating season, water lies nearer the surface. Great care is necessary in order to avoid excessive use of water, as the rise of it may lead to waterlogging the soil and rendering it a mere marsh. This matter is further discussed in "Treatment of Alkaline Lands," page 198.

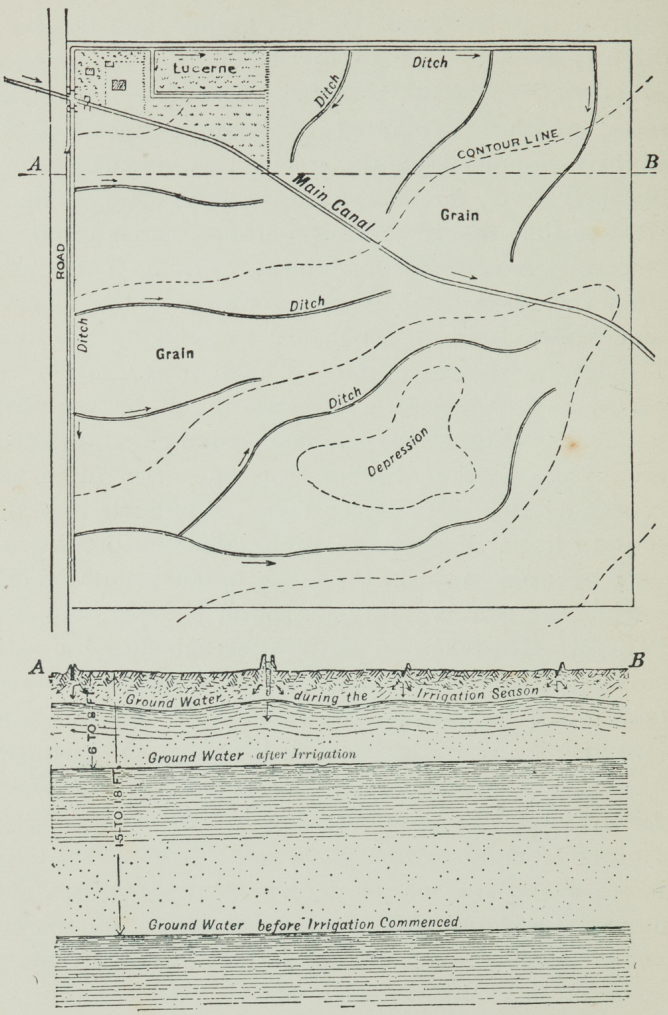

Fig. 49.—Rise of Ground Water following Irrigation.

SUB-IRRIGATION.

Sub-irrigation, or irrigation from beneath the surface, is theoretically one of the most economical and satisfactory methods of applying water to plants. It replaces surface seepage by absorption from below, and to be perfect it should not wet the surface. By this method, the water which is applied to the soil should theoretically have the same temperature, and thus encourage plant growth. As long as the water does not reach the surface it is safe to assume that

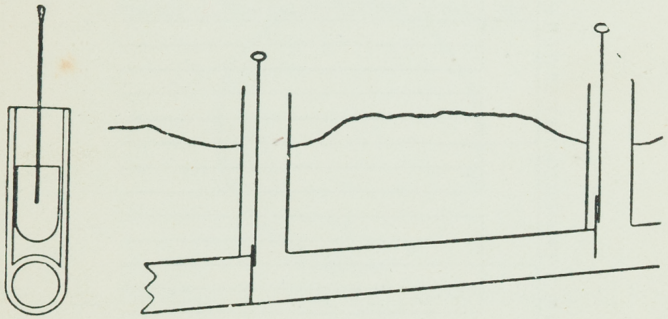

Fig 50.—Pipes and Hydrants for Distributing Water in an Orchard.

the right quantity has been applied, and not a quantity which would drown the soil. To effect this, pipes are laid underground, getting their supplies from distributing pipes. The cost of this method of irrigation is comparatively great, but is more than repaid by the saving in water charges where the duty of water reaches as high as 500 to 1000 acres per second-foot. This method has been most extensively adopted among the valuable fruit lands of Michigan and

Southern California, which are usually divided into orchard lots of from 10 to 20 acres each. For annual, or root, crops, small perforated pipes, as shown by Fig. 50, are used. This allows a small quantity of water to escape at short intervals. The pipes are connected with lines of pipes leading from the reservoir or source of supply, and are laid 12 inches or more beneath the surface.

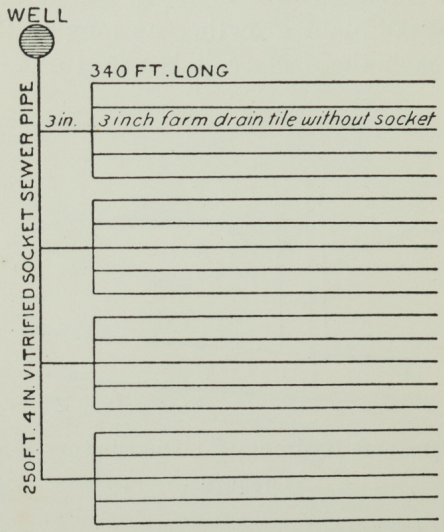

Fig. 51.—Plan of Sub-Irrigating System.

Fig. 51 shows a plan of a small sub-irrigation system successfully used in Kansas, and may be taken as typical. Three-inch pipes are laid 15 inches below the surface and 10 feet apart. Cement is used to close the joints, with the exception of an inch or so on the lower side of the pipes, allowing a small quantity of water to escape at this point. The pipes are

supplied with water at the rate of about 17 gallons per minute. The pipes are laid at a grade which will discharge any excess of water following rainfall. The success of this method is largely ruled by the nature of the subsoil and the soil itself. If the former is very porous, the water may sink away without reaching the surface.

Although burned-clay pipes are preferred, being permanent, other material has been used—such as galvanised sheet-iron. Fig. 52 shows a section of one. The iron is bent so that an open seam is formed at

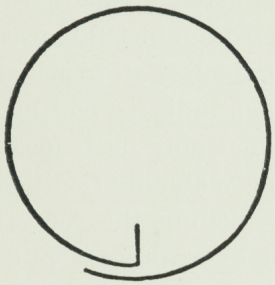

Fig. 52.—Section of small Galvanised Sheet Iron Pipe.

the bottom (smaller than shown in the drawing), through which the water will escape at a moderate velocity. In strata that will pass the water horizontally, and the other conditions being favourable, this method of irrigation has been most successful.

Sub-irrigation exists naturally where there is a free circulation of underground water sufficiently near the surface to supply the requirements of crops. Although the ground may not be actually saturated, enough moisture is transmitted to nourish the plants without over-saturating or waterlogging the soil. Sub-irrigation areas often exist in broad valleys along a creek

from which the water finds its way outwards beneath the surface. They are sometimes found upon easy side-slopes, resulting from water from a creek tending to form springs near the edge of the valley. (See page 115.)

Return Waters.—A portion of the waters of irrigation evaporates. Another portion is absorbed by vegetation, and escapes to the air through the leaves, and is the portion that has accomplished the aim of irrigation. Another portion is lost to the irrigator by sinking into the ground out of the reach of the plants, and is so much wasted element. It is not always practicable to guard against this waste, but it may be broadly stated that all waters which escape over or beneath the surface indicate bad management. This escaping water is not only itself lost, but it may carry with it, in solution, valuable fertilising salts or plant food, thus impoverishing the soil. Sometimes, however, this scouring or washing is valuable, as when the soil is strongly alkaline, and it is necessary to get rid by drainage of the excess of injurious matter.*

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* See " Treatment of Alkaline Lands," page 198.

TREATMENT OF ALKALINE WATERS

When first artesian water flowed in Australia in enormous, unlooked-for quantities, onto the parched surface of the land, a jubilant optimism was engendered regarding its great prospective value; but the waters are not perfect—although great in quantity, they are, like some of the river water, not perfect in quality. Use has shown that they are more or less impregnated with deleterious mineral elements derived from the rocks in which they have lain.* Careful analyses have, however, shown that the waters vary in degree of impregnation, and are, when compared with similar waters of other countries, but moderately affected by the injurious alkaline elements, so as to be in reality better adapted for the growth of plant life. Much knowledge can be gained in substantiation of this, and on the subject in general, from the exhaustive examinations made by Mr. E. E. Oliver, Department of the Punjab, India, and by Professor E. W. Hilyard, University of California—both leading authorities. In both these countries, the " reh " in the former and the " alkali " in the latter have been matters of actual experience and investigation; while, in Australia, investigation has been made on a very limited scale.

An examination of the conditions which obtain in America and India show that those existing here are

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* See " Ocean Outlet and Discharge," page 66.

widely different, and that the dreaded efflorescence need not be feared, even after prolonged use of the water on our irrigable lands, provided proper care in the use of the water, a proper system of drainage, and abundant tilth be observed. This has been shown by the successful production of most valuable cereals, vegetables, and fruits at the Government artesian irrigation farms, especially in New South Wales, which have been under scientific, continuous cultivation with bore water for from eight to ten or twelve years.

THE TREATMENT OF "ALKALINE LANDS."

American experience is as follows:—

Alkali is not only produced by irrigation with some artesian waters, but already exists in the soil in many inland districts of sparse rainfall (as in the "saltbush plains" of the central portion of Australia, notably in New South Wales, Queensland, and South Australia), being a chemical element of the decomposed strata where the rainfall has not been sufficient to wash out the salts. It is frequently one of the greatest bugbears a farmer has to contend with in his tillage operations. The soil of other portions of the States is not troubled in this way, and is too often deficient in alkaline salts, for *no soil is productive when these ingredients are entirely lacking.* It is in an excess of the accumulation wherein the danger lies. Chemically considered, alkali is one of a class of caustic bases—soda, potash, ammonia, and lithia—the distinguishing peculiarities of which

are solubility in water, the power of uniting with oils and fats to form soap, neutralising, reddening several yellows, and changing reddened litmus to blue. Fixed alkalies are potash and soda. Vegetable alkalies are known as alkaloids, and volatile alkalies—so called in distinction to fixed alkalies—are composed largely of ammonia. The principal compounds, or salts, of the alkalies with which soil is impregnated are Glauber's salts, or sulphate of soda, washing soda, or carbonate of soda, and common salt. In much smaller proportions are found sulphate of potash, phosphate of soda, nitrate of soda, saltpetre, and even carbonate of ammonia. A majority of the last five are recognised fertilisers. The most injurious of the three principal salts is the carbonate of soda. Its property of combining with vegetable mould, otherwise known as humus, and forming with it, when dry, a black compound, has given the name of black alkali lands to those of which it is the principal saline constituent. In time of drought these can readily be distinguished by the dark rings left on the margin of dried-up puddles. As Glauber's salt and common salt do not possess this property, the soils impregnated with them remain chiefly white, and are known as white alkali lands.

Formation of Alkaline Soils.—Alkali is, like other minerals, a natural element of the earth. When, as pointed out, the rocks on the ranges—or what were formerly mountains—became decomposed or pulverised, and the sediments were washed down on to the plains, they brought the alkali with them and deposited in the soil. The same alkaline soils are formed everywhere in the world, but in countries having

abundant rainfall they are washed through the soil into natural drainage,* while in regions where rainfall is deficient the scant moisture carries them down only a little way into the soil, from which they rise to the surface by the evaporation of water, and are thus accumulated at or near the top of the soil. It is there that nearly all the damage is done. The water in the depths of the soil is rarely strongly enough impregnated to hurt the roots of the plants directly. The alkali is all through the soil, but its effect is usually worse within a few inches of the surface. It rises to the surface with each wetting of the ground, as a wick. Different wicks will raise water, or oil, to different heights, according as they are closely woven or loose, like candle-wicking. The close wicking will raise the fluid higher in the end, but it will raise to the highest point more slowly than the loose wicking. Just so in the soils—the close ones will raise the soil water from a greater depth than will the loose, sandy ones, but the latter will bring it up quicker to the full height to which it can rise.

Soils Containing Alkali.—Alkali is always worse in clay soils than in sandy ones. This is because it rises to the surface from a greater depth. In the arid country, the rains often wet the soil only a few inches deep, and the alkali forms at the bottom of the moisture, and makes hard cakes, called hard-pan, which is soil full of alkali packed hard. We rarely come in contact with alkali on sandy soil, and if it should prevail in such soils, it would do no special harm. The action of the weather for ages has caused it to leach out as rapidly as it is formed.

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* See Land Drainage," page 243.

Waters Carrying Alkali.—Besides some artesian waters, there are some kinds of surface or river waters which it is not advisable to use for purposes of irrigation. Analyses have shown that some of the lake waters are strongly alkaline, and even the waters of some flowing rivers and creeks, if used for irrigation, would deposit alkali.

Alkali is chiefly the result of defective irrigation by permitting evaporation of sub-surface water, thereby leaving alkali on the surface; but the largest proportion of damage is brought about by the rise of the sub-surface water level by lateral soakage from higher ground, and the trouble is greatly aggravated and extended by the extravagant use of water. In irrigating light soils, very small streams of water should be used; otherwise, if the drainage is good, there is danger of washing out the soluble fertilising elements, leaving only the coarse mineral constituents, and rendering the soil less fertile and productive. This precaution is especially necessary when using clear, pure water from springs, or that from artesian wells, which carry ordinarily little of the rich fertilising sediment characteristic of streams which flow for long distances through alluvial regions.

Remedies for Alkali.—The remedies for the improvement of soils surcharged with the neutral alkaline salts—whether naturally or from artesian waters—are thorough tillage, the leaching out of the alkali by irrigation, combined with either natural or artificial drainage, and frequent irrigation of the soil, assuring the intermixture of the surface deposit of alkali with the lower strata of soil, and

thus diluting it and partially neutralising its injurious presence. Cultivation also checks evaporation, and hence lessens the deposits of alkali on the surface. A loose, dry top soil acts as a cushion of earth and air, intercepting the continuity of the upward passage of moisture along the lower plane of cultivation.*

Under the impression that alkaline land is poor in plant food, many farmers have tried the suitability of stable manure and other fertilisers as absorbents of the alkaline salts. As a rule, these applications are not only useless, but even harmful. From their very mode of formation, alkaline soils are exceptionally rich in plant food, so that the addition of more can do no good. In case stable manure is used on black alkaline ground, a pungent odour of ammonia is given off whenever the sun shines, and plants otherwise doing well are thus injured or killed. Potash salts are wholly useless, and add to the alkaline trouble. Potash is always abundantly present in alkaline lands, even in the water-soluble condition. Nitrates are also present in alkaline soils in sufficient amounts for plant growth, and sometimes in excess. Phosphates may be useful, but will rarely be needed for some years. Green manuring, on the other hand, is a very desirable improvement on all alkaline lands, and for this purpose such crops as lucerne, saltbush, and soy-beans can be utilised. Of all grain crops for white or black alkali land there is nothing so good as barley, with rye next in order, and then oats, wheat being most unsuited of all. The Australian saltbushes — described hereafter—have been found, after many years

* See "Saltbush and its Cultivation," page 215.

of experimenting in the United States of America, to be the most satisfactory in every sense as alkali resistants and as forage plants.

The Flooding System.—The most effective means of getting rid of ordinary white alkali is by washing it out of the land. This can be accomplished by digging open ditches at a lower level than the surface of the land to be treated, and carrying them to the nearest natural outlet. Then, by running water over the land into the drains, without allowing it to stand long enough to soak into the ground and carry the dissolved alkali with it, most of the alkali that has been accumulated at the surface will be removed. By repeating this treatment a few times, land can be practically freed from alkali, unless it is exceptionally bad. Another plan is to use a channel plough, the ironwork of which can be made by any country blacksmith, which will run ditches from four to six inches lower than the ploughed ground every 60 to 80 feet across to serve as drains. Another plan—and to my mind the best, although the most costly—is to underdrain the land with circular burnt-clay pipes. These will last more than a life-time, and will certainly run off the alkali.*

This alkali difficulty was got over in a remarkable manner in the San Luis Valley, California, where large areas of land had been injured by alkaline deposits. The formation of the valley is first a surface soil of two feet over two feet of clay and gravel, then eight inches of quicksand, overlying the hard-pan,

*See "Amount of Water Applied," page 135; "Land Drainage," page 243; and New South Wales "Agricultural Gazette," August, 1904.

which is from eight to eighteen inches thick. Below this is forty feet of dry sand. In the waste ditch an inch hole was drilled down to the hard-pan, and a stick of giant powder blew out a hole as large as a barrel; or a safer mode was to bore holes with augers. When the water, black with alkali, reaches the waste ditch, it immediately runs through these holes, and is lost underneath in the sand. The water is kept running as long as it is discoloured. Some of the worst lands in the valley have been reclaimed in this way.

Chemical Antidotes.—When the quantity of alkali is small, any evil effects resulting from its presence may be mitigated by the application to the soil of chemical antidotes. A cheap antidote for most alkaline salts is lime. In some cases, calcareous marl will answer the purpose. When the alkali consists of carbonates and borates, the best antidote is gypsum, or land plaster. These materials should be sown broadcast over the surface, and harrowed in to a moderate depth prior to irrigating. The usual amount of gypsum to apply is from 400 to 500 pounds to the acre. Gypsum is the only known cure for the disastrous black alkali.

Eradication by Vegetable Growth.—It may happen that all the foregoing recommendations will prove ineffective, and to many cultivators they may be inaccessible. The most simple and natural remedy is to absorb the alkaliferous elements in the soil by cultivating certain neutralising crops. Sugar beets are no doubt the best for this purpose, although any of the long-rooted crops will do nearly as well. Potatoes will not answer at all. Any of the sugar-canes are

beneficial, but the grosser feeders, or the leguminous plants, are better. Nothing is better, probably, than *saltbush and lucerne, the great nitrogenous plants of the western country, as these—especially the saltbush, Atriplex semibaccata—shade the ground, and their deep roots absorb nearly all the water and dissolved salts, while on the whole they reduce evaporation to the minimum.* Other recommended crops are carrots, turnips, cabbages, hops, and pea-vines. In orchard-planting, such trees as the peach, pear, quince, apple, prune, small fruits, and the grape, may be set; for the latter cuttings must not be used, and the soil must not be too strong with alkali. It is said that the olive will grow in the black alkali.

The Effects of Artesian-Water Salts upon Soils and Plants.—To the irrigator there are no questions of greater importance than those relating to the effects produced upon soils and plants by the saline constituents of the water which he is applying to his land. Waters may carry salts that act as fertilisers, or they may carry elements detrimental to soil and vegetation alike.

In discussing the effect of any water upon soils and vegetation, it will be necessary to take up each of its saline constituents in detail. There is one other fact which should, at the outset, be set forth clearly, and which is true of every saline substance, however valuable it may be as a fertiliser or as a plant food, and that is the addition of any salt to a soil will not increase the fertility of that soil, provided there is already present a sufficient supply to meet all the requirements of plant growth.

Sodium Chloride.—This salt has been applied to land since time immemorial. It is more beneficial to inland soils where there is a deficiency of the salt. In soils where plenty of this compound exists, further applications are not beneficial. In its action, common salt is not a direct fertiliser, since plants, as a rule, require little sodium. Small quantities of chloride, also, will meet all requirements. It is one of the so-called "indirect" fertilisers. Its value, when applied to soils, may be attributed to the following causes:—

1. It acts upon the undecomposed rocky constituents of soil, liberating lime, magnesia, and phosphoric acid for plant use. Its greatest action is upon lime, and then upon the other substances in the order named. These substances, which in their undecomposed state were mostly combined as insoluble silicates, through the kindly offices of salt assume a soluble condition, in which form plants can readily assimilate them.

2. Salt also tends to check a too-rank growth of stalks and straw, and it is often applied to over-fertile soils for this purpose. It is also mixed with other powerful fertilisers, such as guano, to modify their action. It gives the best results upon grains, grasses, cotton, hemp, etc. It is not applicable to potatoes, since it diminishes the yield and makes the tubers waxy. An overdose of salt is fatal to all vegetation. The only remedy is efficient and thorough drainage.

Sodium Sulphate.—This salt is a valuable fertiliser for cereals, grasses, clovers, etc. This sulphate, as well as those to be mentioned hereafter, acts on soils as an oxidising agent. By this action, nitrogen in

nitrogen compounds is changed into ammonia, carbon into carbon dioxide, etc. The ammonia thus produced is seized upon by the nitrifying organisms in the soil, and converted into nitrates. It is from these forms that plants largely receive nitrogen for building up their albuminoids. Moreover, these albuminoids contain sulphur obtained from the breaking-down of these same sulphates. Sodium sulphate is one of the chief ingredients of the so-called "mild," or "blind" alkali, which occurs as an incrustation in low places in various parts of the State. These places are mostly small, and their salt can be removed from them by drainage. By means of deep ploughing, and by the admixture of coarse manure to decrease the capillarity of the soil in those places, large crops of grasses may be obtained. But the *permanent cure of all soils overcharged with this salt is drainage.*

Sodium Carbonate.—This compound has a favourable effect upon vegetation when it is present in small quantities in soils rich in organic matter. It furnishes a readily salifiable base to unite with the nitrous and nitric acids produced by the nitrifying organisms present in all fertile soils. The organisms convert this carbonate into sodium nitrate and nitrate—valuable fertilisers. But when present in large quantities the sodium carbonates constitute the dreaded "black alkali" which occurs in undrained places in California, India, Australia, and elsewhere. Black alkali is pernicious in its action upon both soils and plants. It puddles clayey soils—or, as it usually termed, turns them into "gumbo." It also dissolves the humus of fertile soils, which it leaves in black rings or patches, as the water evaporates from places where it has been

standing in puddles. It is owing to this circumstance that it has received the name of black alkali. Its action on plants is corrosive—actually eating off the plant at the crown. Moreover, this salt—as well as all of the sodium salts—has a tendency to creep upward. The rising soil waters bring them to the surface, and leave them as a white incrustation on the surface of the soil. Waters carrying much sodium carbonate should not be used for irrigation unless the land is first thoroughly under-drained. (See "Farm Drainage," page 250.) Water showing an average of .0036 up to .0102 parts of sodium carbonate per 1,000 is excellent for irrigation. .0334 of sodium carbonate per 1,000 would require a corrective such as gypsum. An amount that would be safe in one place might prove disastrous in another. This uncertainty is due to many factors—such as the saline constituents already in the soil, and various climatic conditions, such as rainfall, winds, humidity of the atmosphere, etc. The mechanical conditions of the soil and subsoil, together with the natural drainage, constitute important factors in the problem. Soils containing an excess of sodium carbonate may be reclaimed by application of gypsum, by drainage, or by both. There is a reaction between the gypsum and the soda carbonate, whereby the carbonate is converted into the sulphate, in which condition it becomes mild, while the gypsum is changed into lime. Drainage simply carries the lime away.

Magnesium Sulphate.—Magnesium compounds are indispensable to plant life. They form an important part of the herbaceous and woody parts of plants, and occur in the ashes of all seeds. It is in the seeds,

however, that magnesium compounds occur most plentifully.

Here I should like to quote from a report made in 1905 by Mr. H. M. Wilson, C.E., Irrigation Engineer to the United States Geological Survey:—

ALKALI AND DRAINAGE.

Harmful Effects of Irrigation.—When irrigation is practised without proper attention to drainage, it is liable to result in the following evils: (1) Production of alkali or flocculent salts on the surface of the ground; (2) souring or water-logging of the soil due to supersaturation; (3) fevers or other injurious effects, the result of the same cause.

Alkali.—The white efflorescent salt known as "alkali" is to be found in many portions of the West, both as the result of irrigation and occurring naturally over extensive areas. This salt has been analysed, and found to consist chiefly of chloride (common salt), carbonate (sal soda), and sulphate (Glauber's salt) of sodium. The relative proportions of these vary greatly, but the latter is nearly always present, and predominates, ranging from 5 to 75 per cent. There is generally present a small amount of accessory salts, as manganese sulphate and the salts of potassium. Of the latter, the nitrates and phosphates are of value, as they are ingredients usually supplied in fertilisers. Their presence therefore indicates the occurrence of sufficient plant-food in the soil to render fertilisation unnecessary.

Perhaps the most harmful of alkaline salts is sodium carbonate, commonly called "black alkali." This is more commonly found in the warmer climates and in moist, close soil, rich in humus, such as is found in the San Joaquin Valley of California, and it is mainly found in low ground, where the alkali occurs in spots. It is greatest in amount near the centre of the spots, while potash, on the contrary, increases in amount near the margin. The effect of alkali is to kill all vegetable matter, and to render the soil barren and unproductive.

Causes of Alkali.—Where the natural drainage of the country is defective, and the strata underlying the surface are impervious, or the soil not deep, irrigation or rainfall causes the subsurface-water plane to rise to such a height that finally the soil becomes saturated. Evaporation then takes place from the surface, and as this process continues there is left on the soil the salts contained in the water. Thus, the more water that evaporates from the surface the more alkali will be deposited, and increased rainfall, or irrigation, will increase the amount of alkali. It is thus seen that the direct cause of the production of alkali is the rise of the subsurface-water plane due to defective drainage and its evaporation from the surface. Prof. E. W. Hilgard's experiments show that the main mass of alkaline salts exists in the soil within a short distance of the surface, and that the amount of these salts is limited. He therefore asserts that the bulk of alkali salts is accumulated within easy reach of under-drains, and, if once removed, not enough to do harm will come again from below.

Water-logging.—Where the rise of water from the

sub-surface, or its addition to the surface from natural causes or irrigation, is more rapid than the losses by evaporation or drainage, the water stands in pools, and the soil becomes soft and marshy. Like alkali, water-logging is directly traceable to defective drainage and the careless use of water. Where the conditions are sufficiently well-balanced for drainage to prevent the rise of the sub-surface water to within 10 or 15 feet of the surface, continued irrigation produces good results by soaking up the lower strata and giving an abundance of water near the surface for wells and for moistening the deeper-rooting plants.

Prevention of Alkali and Water-logging.—Several preventives for the rise of alkali, or the excessive soaking of the soil, have been recommended, and some have been employed with perfect success. Since evaporation is the cause of the rise of alkali, the chief preventive is by reducing this to the lowest point. This may be done by mulching the soil. It is also possible in some cases to cultivate deep-rooting, or such plants as shade the soil, and reduce the amount of evaporation, or such as are least harmfully affected by its presence, thus mitigating the evil, and permitting some use to be made of the land. Irrigating only such lands as have good natural drainage, and exercising care not to interfere with this, is one of the best and surest preventives of the production of alkali and water-logging. The introduction of artificial drainage produces the same effect, while, in a lesser degree, the same result may be obtained by the use of deep ditches or furrows, which themselves act as drainage channels. When the quantity of alkali is small, the evil effects resulting from its pre-

sence may be mitigated by the application of chemical antidotes; and, lastly, relief may obtained in some cases by watering the surface, and drawing off the water without allowing it to soak into the ground. This system of reclaiming the land by surface washing and drawing off the salt-impregnated water is known as "leaching."

One of the most effective methods for the prevention of alkali is the judicious and sparing use of water in irrigation. If the least amount of water necessary for the production of crops is applied to the soil, the soaking of this with water will be a much slower process, and may not result in over-saturation, even though the drainage be defective.

Chemical Treatment.—A cheap antidote for many alkaline salts is common lime, while neutral calcareous marl will answer in some cases. When the alkali consists of carbonates and borates, the best antidote is gypsum or plaster of paris. Notable experiments have been made by Prof. E. W. Hilgard, which prove the value of gypsum in neutralising the "black alkali" or carbonate of soda. Soils heavily tainted with this alkali can be rendered profusely productive by the use, once for all, of a ton of gypsum per acre. This is more effective when applied at the rate of about 500 lbs. per acre per annum, in connection with some seeding at the same time; for the slightest growth aids in shading the ground and preventing an injurious release of salts by evaporation. Gypsum, however, cannot be used on alkali without water; its action must be continued for several months, and through two or three seasons. It takes, moreover, several weeks before immunity is secured.

and therefore the dressing of gypsum should be applied in ample time before the seeding; and therefore the soil must be well cultivated and ploughed in, and promptly followed by irrigation.* When there is not a good natural drainage, under-drains must be provided in reclaiming alkaline soil by chemical treatment. Gypsum acts, practically, by converting the harmful carbonate of sodium into the less harmful sulphate of sodium, in the presence of water and with the aid of thorough mixing by ploughing, and these salts are washed through the soil, and are carried off into natural drainage channels, or, if the locality treated be a sink, concentrated in its bottom. A cheap form of under-drain which has been used with success consists of simple boards placed together like the letter A at a depth of about three feet beneath the surface. These drains should be so laid out as to unite, and discharge either into a sink-hole or drainage channel. Mere surface treatment without drainage in soils strongly impregnated with black alkali, would change the latter to white alkali, but would still leave too much of this in the soil for the growth of useful vegetation. It has been found that ploughing in a great deal of straw at the close of the first season, and sowing the same with wheat and barley aids in hastening the reclamation of the land, since the straw keeps the surface loose, and enables the grain to germinate.

* This gypsum treatment only applies to the worst or "black alkali" lands, whether produced naturally or by defective irrigation. Even the most highly-charged artesian water may be rendered from the start innocuous under proper cultivation and drainage.

After three years of treatment by this process, 45 bushels of oats, and a similar crop of barley, was produced on one of the worst alkali spots in Tulare County, California. It should be distinctly understood that wherever black alkali exists the use of stable manure to effect the loosening of the soil is harmful, by setting free corrosive ammonia vapours.

Mulching and Leaching.—An excellent preventive against evaporation from the soil surface, and the consequent production of alkali, is by "mulching." The best mulch is a well and deep tilled surface soil, which is kept so constantly stirred that a crust is never allowed to form. As a result, evaporation is reduced to a mimimum, and the alkali remains distributed throughout the whole of the tilled layer, instead of at the surface as a hard crust, where the bulk of the damage is done. Ploughing in large quantities of straw produces also an effective mulch. The depth or thickness of this protective tilled layer is of the utmost importance, for thereby the strong surface alkali is diluted with the largest possible mass of subsoil. After a proper tilling to a depth of, say, 10 to 12 inches, it requires a long time for the salts to come to the surface again in sufficient amount to injure the crop. As the chief desideratum in mulching alkaline land consists in maintaining a deep and loose tilth during the time when evaporation is active, this implies the growing on such lands of hoed rather than grain crops — preferably deep-rooted crops. Leaching is not infrequently employed, more especially in Europe, to mitigate the harmful effects of alkali. This is practised by building temporary embankments around the land and then flooding it,

after which the salt-impregnated waters are rapidly drawn off.

SALTBUSH AND ITS CULTIVATION.

There are few antagonistic conditions for which there are not more or less effective remedies. In accordance with that precept, it is proposed to show that artesian water, *when even of an exceptionally alkaline character*, may be made to produce most valuable vegetation, although such water may be unadapted for raising crops which flourish under natural irrigation from rainfall or from river supplies. It seems necessary to do this, because an erroneous impression undoubtedly prevails in some quarters that the water is good only for watering stock.

Native Plants of Alkaline Soils.—Among the plants which grow on alkali soils there are many which are valuable for forage. The late Baron von Mueller, the eminent botanist, first drew attention to the cultivation of such plants. He referred to the fact that the vegetation of extensive areas in the central portion of Australia—notably in western New South Wales, Queensland, and South Australia—consisted almost entirely of *Atriplex*. The fact was known that these "saltbush plains" would carry and maintain, in better condition, a larger number of sheep and cattle than would be supposed, judging from the limited grass vegetation. Stock grazed on saltbush was also remarkably free from parasitic diseases, and it was assumed that the plants had tonic properties, owing

to some bitter principle, together with the large amount of salt found in the leaves.

Through von Mueller's efforts, the cultivation of saltbushes was undertaken in South Africa, North-West India, and later in California, and everywhere the plants showed remarkable adaptation to saline or alkali-impregnated soils.

Fig. 53.—Atriplex Vesicaria.

To show the small beginnings of an experiment, Mr. E. G. Alston, the well-known experimental agriculturist of Cape Colony, planted six seeds of *Atriplex halimoides*, which had been obtained from Baron von Mueller. Two of the seeds germinated, but one plant died before reaching maturity. The seeds from the single remaining plant were saved, and tried the following year on a larger scale. This one plant

has been the mother of nearly all the stock of a species now widely cultivated by sheep-men in all the South African colonies.

Saltbushes Native to Australia.—There are a large number of Australian saltbushes, all of which would pay under systematic cultivation. *Atriplex semibaccata* is a much-branched perennial, which forms a thick mat over the ground to the depth of a foot. The branches extend from eight to ten feet, so that one plant will cover an area of twenty feet in diameter. The leaves are about an inch long, broadest at the apex, and coarsely-toothed along the margin. The pulpy flattened points are tinged with red at maturity, but dry out as soon as they fall from the plant. They are produced in enormous numbers, and ripen continuously for three or four months, or, in situations where growth is perennial, throughout the year. Some practical stock-men have had good results in establishing this favourite saltbush on alkaline soil by sowing the seed on the ground, when it was met with heavy rains, and at once driving a flock of sheep over the land, and thus treading the seed into the soil. Sheep are especially fond of this saltbush, and cattle relish it if combined with other food. Many pastoralists are of opinion that the valuable qualities of the Australian wools have been largely due to the abundance of this and other saltbushes, and that, if they were exterminated, the value of the wool would tend to decrease.

The Fodder Value of Saltbush.—Mr. F. B. Guthrie, Government Analyst, New South Wales, says ("Agricultural Gazette," Vol. 8):—"The value of saltbush as a fodder is too well known to require special refer-

ence at this time of day. The main object of the following analyses was to compare the feeding value of the plant in its native state in different parts of the State with one another, and with the plant grown as a cultivated crop.

	Grown at Wagga Farm (Cultivated).	From Bourke (Uncultivated).
Moisture	75.11	56.73
Oil	.56	.67
Digestible Fibre ...	8.21	11.59
Soluble Albumenoids ...	3.29	3.93
Insoluble ,, ...	.50	1.76
Soluble Ash	2.56	3.54
Insoluble ,, ...	5.77	14.14
Chlorophyll, Amides, and	.15	2.04
Other Extractives ...	3.85	5.60
	100.00	100.00
Total Nitrogen	.74	1.20
Amide	.25	.36
Percentage of Common Salt in ash	36.6	56.6

The great difference in the percentage of moisture is due to the fact that the Wagga specimens had not so far to travel, and were more carefully packed. The most striking differences here are the larger proportion of oil and digestible fibre in the cultivated specimen, and the lower proportion of ash. Particularly remarkable is the diminution of common salt in the cultivated sample.

For the sake of brevity, only the mean of the analyses of the Bourke and Hay saltbushes will be given, and, to avoid the discrepancies occasioned by the different degree of freshness of the samples, I have calculated all on the basis of 75 per cent. water, which fairly represents the composition of saltbush.

	Average of 3 Samples from Bourke.	Average of 3 Samples from Hay.	Sample from Wagga Farm.
Water ...	75.00	75.00	75.00
Oil	.47	.61	.56
Albumenoids ...	2.35	2.52	3.07
Carbohydrates ...	10.55	7.78	12.13
Woody Fibre ...	3.52	3.91	3.30
Ash	8.09	10.11	5.94
	100.00	100.00	100.00
Percentage of Common Salt in Ash...	53.06	51.03	36.06

The following gives for comparison the composition of some ordinary green fodders, taken from the "Farmers' and Fruitgrowers' Guide":—

	Maize-Fodder.	Sorghum.	Lucerne.	Timothy Grass.
Water ...	7.03	79.4	71.8	61.6
Oil	.5	.5	1.0	1.2
Albumenoids ...	1.8	1.3	4.8	3.1
Carbohydrates ...	12.2	11.6	12.3	20.2
Woody Fibre ...	5.0	6.1	7.4	11.8
Ash	1.2	1.1	2.7	2.1

A comparison of the above shows that the saltbushes take a high place amongst green fodders, the amount of carbohydrates and albuminoids being high, and the woody fibre relatively low. The high content of mineral waters, especially of common salt, is, of course, characteristic.

The plant may be propagated from cuttings as well as from seed, and this method is to be preferred whenever the land contains much alkali. The seeds will germinate in the presence of an amount of soda salts which would entirely prevent the growth of cereals, although there is, of course, a limit to the amount of alkali the plant will tolerate, as in the case of lucerne or wheat.

Atriplex semibaccata is the most promising of the Australian saltbushes for cultivation, both because of its hardiness and the bulk of fodder produced. It is of special value for cultivation with artesian water, as it has a procumbent habit, with spreading stems and leaves, affording valuable protection to the soil, and thus preventing undue evaporation and the consequent formation of alkali on the surface, as well as absorbing the injurious salts of the soil.

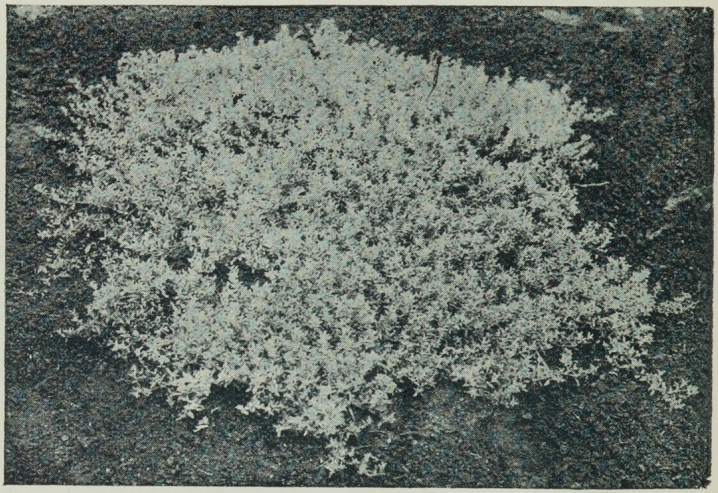


Fig. 54.—Atriplex Semibaccata.

The forage contains 11.6 per cent. of crude protein in the air-dry substance, as compared with 14.3 per cent. for lucerne. Thus, 100 lbs. of the dry substance will contain 8.7 lbs. of digestible crude protein, as compared with 10.6 lbs. in lucerne. The nutritive ratio is 1 to 4.5 for saltbush and 1 to 4.1 for lucerne, so that it would seem to have nearly equal feeding value.

In discussing the merits of saltbushes as fodder, it must not be forgotten that they possess natural advantages over the ordinary cultivated crop or pasture grasses. They flourish on land which will not support other nourishing plants; they resist drought to an exceptional degree; are indigenous, and require no cultivation; are relished by stock, and are exceedingly prolific and easily propagated. It would appear, however, in spite of the universal recognition of these facts by stock-owners, that there is some danger of these plants becoming less abundant than formerly, through overstocking and other causes. Both stock-owners and visitors in the western country during the last severe drought lamented this fact. It seems, therefore, that it is a proper time to call attention once more to the high nutritive value of these plants by careful analyses and comparison with other fodder crops. In California they have imported a number of species from Australia, for the purpose of experimenting with the alkaline soils of that State. This is what Professor Wickson, of the State University, says of the *Atriplex semibaccata*, the variety which has given the most successful results in California:—

"*A. semibaccata* (a variety of prostrate growth) thrives splendidly in alkali soils which will not retain other useful growth. It attains a growth in one season of 16 feet in diameter of thick matted growth, yielding 20 tons of green feed to the acre. Two cuttings, of 20 tons each, can be made in one season." If it is worth while to import saltbush seed for cultivation in California, it is surely worth while to encourage these plants in our arid districts, if only to the

extent of preventing them from being eaten down by overstocking. It should be possible, if it were seriously attempted, to assist their propagation materially, as they grow *readily and prolifically* from seed, from cuttings, and from the root. In good seasons there seems no reason why saltbush should not be cropped as lucerne, and conserved as dry fodder for times of drought.

The Cultivation of Saltbush.—The following directions are given by Mr. J. Duff, ex-Inspector of Forests:—

"The plan of operations is as follows: Plough to the depth of 20 to 40 inches, and harrow along the dividing fences of each paddock on the holding, strips of land one chain wide, afterwards erecting inner fences so as to exclude all live stock therefrom. Then procure cuttings from the old wood from a quarter to half an inch in diameter and one foot long, and plant the cuttings in rows eight feet apart, and the same distance between the cuttings in the rows in the enclosed areas. The ground should be broken fine with a spade where each cutting is planted, and the cuttings afterwards planted and rammed firmly in the soil with a dibble, leaving only one inch to one and a half inches of their tops above ground. Cuttings of the young wood, or tops of branches, would require to be struck in boxes, in a mixture of equal parts of leaf mould and sand, and placed in a glass frame, and the saltbush seed would also require to be raised in boxes under glass, as the young wood is too soft and the seeds too small to be grown with any degree of certainty of success in the open ground.

"Plantations of saltbush one chain wide would con-

tain seven rows of plants at eight feet apart, leaving five feet between the two outer rows and the fences. and this would give an average of 49 plants to the square chain. In the autumn of the first year of planting, the saltbush cuttings would have grown to the height of four to five feet, and might then be clipped with hedge shears, the clippings raked into heaps, and thrown over the fences on either side of the plantation, to feed the stock in the paddocks.

Fig. 55.—Enchylæna Tomentosa (Barrier Saltbush).

"Cuttings could also be procured from the saltbush on the expiration of the first year after planting, for forming additional plantations, and I have much more faith in the success of growing the saltbush from cuttings of the old wood and layers than from the

young wood and seeds, as plants from the two latter would require to be raised and grown to a size fit for planting out by a practical gardener. At the end of the first year of planting, all the branches could be layered, an operation easily performed by forming a drill about four inches deep in the soil for each branch, pegging them down in the drills, and covering as much of the branches as possible with soil, leaving their tops above ground. The layers root readily, and in a few months could be cut off, dug up, and planted in new enclosures, which work should either be done in autumn or early spring, and, when one plantation of one chain wide by six chains long, containing nearly 300 plants, has been established, an abundant supply of cuttings and layers could then be obtained for forming additional plantations as required.

"To preserve the saltbush from destruction, and prevent its total extinction, it is absolutely necessary to grow it in enclosed plantations, as herein recommended, only cutting the young shoots off the plants for fodder during periods of drought (which does not injuriously affect the plant), when grass and other herbage are insufficient to keep the stock alive."

It is well known to pastoralists that the saltbush, which is a very brittle-wooded plant, is quickly destroyed by being broken or eaten down too closely, and by all young shoots being eaten off as they appear, so that the necessity of growing it in enclosures will be obvious; and it is no exaggeration to state that in all stocked runs wherein the saltbush grew it is now almost extinct.

For producing the best qualities of beef, mutton

and wool, it has been proved that no other fodder plants or grasses equal the saltbush, and bullocks fed upon the Murrumbidgee saltbush flats, on the stations near Narrandera, have realised the highest prices in the Melbourne market; and it has also been proved that animals fed upon the succulent saltbush do not require nearly as much water as if fed upon any other description of herbage. The permanency of enclosed plantations, saving of stock, and keeping the animals in fair condition during periods of drought, would compensate pastoralists tenfold for the outlay in forming these plantations, and would be the means of alleviating much suffering and distress of both pastoralists and stock.

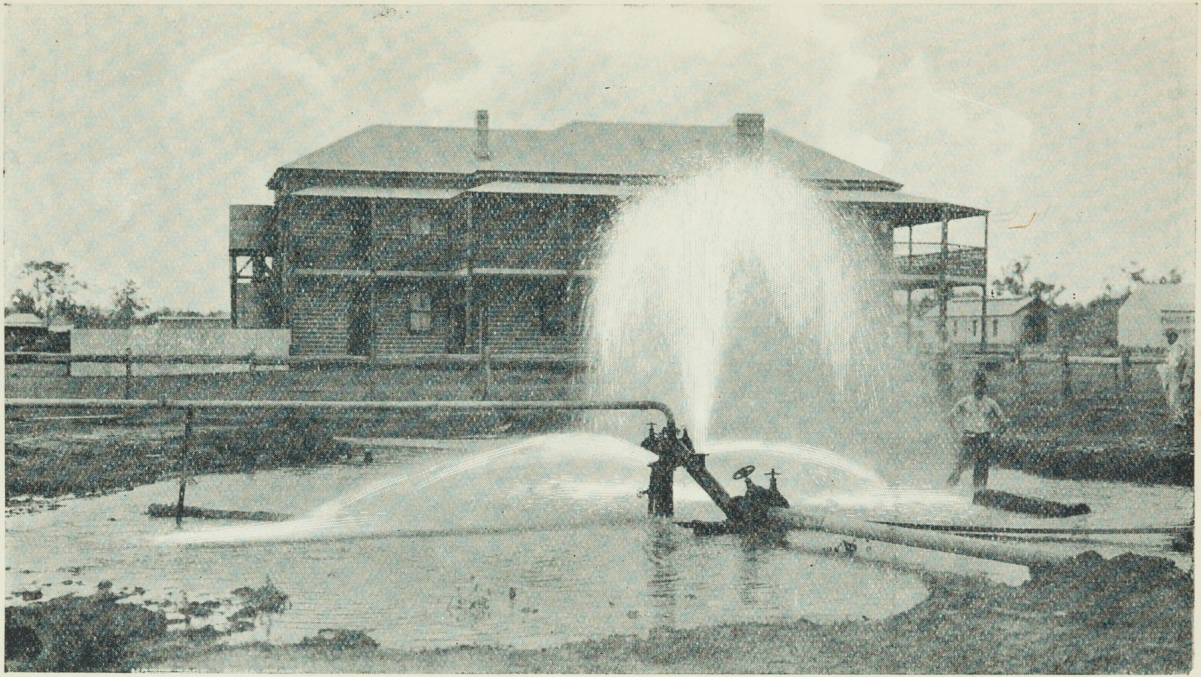
It will be seen from the above particulars that there is a most satisfactory way of utilising even highly-charged alkaline waters. Nature's great law of compensation thus again asserts itself. The condition of a parched and barren surface is not only neutralised by a free flow of underground water, but that water, alkaline as some of it is, may be made, by means of irrigation, the main agent in the production on the surface of one of the most valuable known species of plant food for the sustenance of stock, the health and maintenance of which has been, in the past, at the mercy of the devastating droughts to which the country is periodically subject.

RESULTS IN IRRIGATION WITH BORE WATER (with Instructions as to Management).

Moree Artesian Irrigation Farm, New South Wales.—To Mr. W. R. Fry, Manager of this farm, a former student of the Hawkesbury Agricultural College, I am indebted for the following particulars of work he has very ably carried out at the farm:—

The experimental farm at the Moree Bore has been established eight years, and the soil is still producing good crops. During the great drought (1902) green fodder to the value of £300 was sold from one small paddock, while on the opposite side of the road special train-loads of fodder were being transhipped to teams for the starving stock between Moree and the border of the district. During this period many owners paid over £1 per head to keep their breeding ewes alive, the fodder costing, delivered, from £17 to £20 per ton, while, with the use of bore water, which was comparatively plentiful, green fodder could have been produced at a cost of 5s. to 10s. per ton.

One of the most essential matters for successful irrigation is to have the ground levelled or graded, and this grading should be done, if possible, before any crops have been sown. Although the black soil plains appear to be very level to the eye, many lumps and hollows will be found when watering, after which the defects can often be remedied without very much surveying or sighting. Irrigating uneven ground is very unsatisfactory, for not only are there many blank spaces in the crops, caused by too much or too little water, but the operator will have to expend much



Moree Government Artesian Bore, New South Wales.

time and patience in wading knee deep in black mud on the low spots, in order to coax the water on to the dry portions. Continual watering of uneven lands will make the low spots sour and cold, and in time, by drowning the nitrifying bacteria, render those spots sterile. Grading is best done by means of a scoop of the "Tumbling Tommy" or "Buck-scraper" pattern (see Fig 22, p. 162), as used on the Government farms.

Wheat for Hay.—On the black soil, especially in the virgin state, the growth is apt to be rather coarse; therefore it has been found advisable to sow at the rate of 1½ bushels per acre. If time can be spared, the land should be ploughed in the spring, and left to lie rough until March, when it should be cross-ploughed and harrowed. Seed should be sown in April or May, and if the soil is dry, and no rain falls within a month, it should be irrigated to bring the grain up not later than June. In newly-ploughed clay land the watering furrows may be left 10 to 15 feet apart, with a very gradual fall, and the water, which should be brought on to the field at the highest point, should be allowed to soak slowly down the furrows in small streams. If the water is run quickly down the furrows, it is liable to puddle the sides, and will not soak. The object should always be to let the water soak through the deep furrows, and never to rush or flood over the land. A week or so after the irrigation, or as soon as the horses can get on the ground, the crop should be harrowed. This harrowing destroys the crust, fills up the cracks, and checks extensive evaporation. If the crop is too forward, and

threatens to come into ear during the frost, it is advisable to either mow it down or feed off by sheep. This will check the top growth, and cause the crop to tiller out and make finer hay. After the sheep are removed the crop should be again harrowed, and, if the weather is dry, it may receive a watering in August; but, as evaporation is not very great during the winter months, the second watering can generally wait until September, or even October. The time of watering depends, to a great extent, upon the actual rainfall. A crop, say, at Wilcannia, with a 10-inch rainfall, would naturally require more irrigation than one at Moree, with, say, 20 inches annual rainfall. The hay crop will be ready for cutting about November, and the certain yield may be anything from 2 to 4 tons per acre.

Wheat for Grain in the artesian country is best sown about May, and should be drilled in at the rate of 45 to 60 lbs. per acre. If rain does not fall to time, the final watering should be given just as the crop is about to flower, which will cause the heads to fill up; otherwise the grain will be pinched.

Oats are treated like wheat, except that they may be planted later, and require a thicker seeding. The Algerian oats have given the best results. A plot sown in June, on black soil, at the rate of 2 bushels per acre, yielded hay of exceptionally fine quality, whilst adjacent plots of white Tartarian, sown 1 bushel per acre, were coarse and flaggy.

Barley may receive the same treatment, but can be sown earlier—say in March—and two or three cuttings obtained. The crop should be irrigated and harrowed after each cutting. If the winter has been

Moree Bore Irrigation Farm, New South Wales. Five-year-old fruit trees growing on land irrigated for the last seven years with artesian water.

dry, a crop of green vetches will be found exceptionally valuable for breeding ewes or milch cows, but, if it be not intended to use green, the beardless variety should be sown. Experiments in America have proved that barley is one of the best crops to grow on alkali soils; so that this crop could probably be grown with artesian water that would not so well suit other crops.

In Irrigating Fruit Trees and Vegetables, the water should be confined to deep furrows, and allowed to soak slowly. As soon as the ground is dry enough for horses, the soil should be well stirred with a cultivator. Thorough cultivation at the watering is absolutely necessary in order to maintain a good tilth and an even degree of moisture. The five-year-old trees shown on page 230 are growing on black soil which has been irrigated for the past seven years with artesian water; but, owing to thorough cultivation, the soil is in as good, or better, mechanical condition now than it was before irrigation. Yet similar soil can be seen in adjoining paddocks in a very hard and sodden state, owing to indiscriminate flooding with the same bore water for only five years.

Corn-Maize is best sown in drills about four feet apart, and irrigated in furrows. Experiments at Moree have proved that it is best to soak the land after ploughing, but before sowing. When dry, the land should be well cross-cultivated, furrowed, and sown. If maize is sown before watering, much of the seed will fail to germinate.

Undoubtedly the best crop to grow on a station with artesian water is sorghum. From any five acres of

Sorghum, Moree Bore Irrigation Farm, New South Wales (1906). Grown on land irrigated for the last seven years with artesian water.

irrigated sorghum 100 tons of green fodder can, with ordinary care, be produced. At Moree, *Sorghum saccharatium* has grown eight feet high in ten weeks from the time of sowing, and Pearl millet six feet high in the same time. Sorghum should be sown for sheep feed at the rate of 12 to 15 lbs. per acre, and should be planted in the spring, so as to obtain several cuttings.

Lucerne.—This splendid forage crop is perhaps the most prolific under irrigation, provided that a deep, loamy soil is chosen. It has not given general satisfaction on the black soil, as the expanding and contracting nature of the ground retards its growth, and the plant consequently comes into flower at a very low stage. Last year lucerne was cut seven times, but the crop was light. Irrigation by furrows is not so satisfactory for the crop, because after a few years the furrows get waterlogged, and some plants are, therefore, liable to get drowned before the others between them are moist. It is found to be more economical, in regard to both water and labour, to flood the whole area by means of banks or checks. At an adjoining station there is a most luxuriant crop of lucerne, irrigated with bore water, but growing *on an alluvial river flat.* As a crop like lucerne is cut and flooded every few weeks, it is apparent that, where the water is saline, the ground will be injured much sooner than when fewer waterings are required.

On most stations where plenty of land is available, the owner should be satisfied, after getting seven cuttings, say, for ten years, to let the area lie as dry fallow for a year, and then plant with saltbush,

Almond Trees, Moree Bore Irrigation Farm, New South Wales (1906). Grown on land irrigated for the last seven years with artesian water.

which has been proved to be one of the best plants to re-absorb salts. The area would then act as a plantation for seeds and cuttings.

The following is from Mr. Fry's Official Report, 1905:—

Cotton.—This crop has proved very hardy and prolific, and I consider would be profitable to grow, if the raw material could be ginned. The following varieties were sown during November in rows three feet apart, which distance was proved to be too close on this soil for successful horse-cultivation:

Culpepper.—Three feet high; large dark leaves; shed a few pods.

Griffen.—Vigorous-spreading; prolific; light-green leaf.

Russell's Big Boll.—Upright; leaves large, dark, glossy; large pods.

Jones' Re-improved.—Spreading; prolific; red stem; first pods ripe 27th Feb.

Tool's Early-improved.—Similar to preceding; pods ripened March.

King's Early-improved.—Rather dwarf.

Lewis's Prize.—Vigorous, spreading, and upright; most prolific.

Peterkin.—Three to four feet; vigorous; seeds separate early from lint.

The Lewis's Prize proved most prolific, yielding a crop of 1,500 lbs. of raw cotton, or estimated value of lint and seed £16. These plants were irrigated twice during the growing period.

Grasses.—*Paspalum dilatatum* has not maintained its reputation in this district of black-soil plains as a drought-resisting plant, dying out after a few months

of dry weather. Where irrigated, however, the growth is most luxuriant.

An exhibit of products from the farm (including dried and bottled peaches, apricots, plums, figs, sultanas, almonds, cereals, lucerne, hay, sorghum and millet, cotton, rice, vegetables, and citrus fruits) was staged at the late Sydney Show, and excited much favourable comment.

It is encouraging to report an improvement in the mechanical condition of the soil, this being especially noticeable in the orchard, which has been cultivated regularly after watering. The majority of the trees are growing well.

In order to see if the continual irrigation had affected the soil deleteriously, samples were sent to the Departmental Chemist for analysis. Sample No. 1 was taken from land that had been irrigated and cultivated for the past seven years, and sample No. 2 from virgin ground adjoining. The most noticeable difference in the *mechanical* analysis is—as will be seen—in the decreased proportion of clay in the cultivated or irrigated land.

MECHANICAL ANALYSIS.

Sample.	Fine Soil.	Impalpable Matter, chiefly clay.	Moisture.	Volatile and Combustible Matter, mostly organic.
1. Cultivated ...	18.00	71.00	8.13	5.29
2. Virgin Soil ...	13.33	78.35	9.70	6.10

FERTILISING SUBSTANCES SOLUBLE IN HOT H'CL. ACID.

Sample.	Lime.	Potash.	Phosphoric Acid.	Nitrogen.
1. Cultivated ...	.760	.350	.091	.035
2. Virgin Soil ...	.640	.387	·074	.063

Mr. F. B. Guthrie, Departmental Chemist, further reports as follows:—

"The analyses of the soils show that irrigation as practised at the Moree farm has been without effect upon the alkaline content, the cultivated or irrigated land containing no more alkali than the virgin land. The proportion of lime is somewhat higher in the cultivated soil, due, no doubt, to the application of lime to the soil four years ago. The amount of humus, or vegetable matter, is less in the cultivated soil, but the difference is so slight that it is more likely to be caused by the method of cultivation adopted than by the action of the bore water. Green manuring is strongly to be recommended, as it will greatly improve the texture of the soil and render it less liable to crack, as well as supplying plant food. Potassium salts are present in fair proportion, and these are available as plant food. It would appear that the method of cultivation adopted is quite sufficient to prevent any deleterious effects from the use of the bore water." The healthy appearance of the trees and crops at the farm fully supports the chemist's opinion in the laboratory.

The flow of the bore, according to the latest reading, is 837,250 gallons per diem, as compared with over a million gallons eight years ago. This decrease may be due to defective casing, or to some of the water, in coming up *outside* the casing escaping into dry strata between the bottom (2,772 feet down) and the surface, as a small quantity is noticed to bubble up through the gravel around the bore-head. It may be mentioned that other bores in the district (Florida, etc.) have shown an increase in flow during

the last year, which may be due to the increased rainfall in the intake beds since the last drought.

The Moree results have been obtained with the water hot, and not cooled off and aerated.

Aeration.—It is said that for successful results with bore water it is necessary to first cool and thoroughly aerate the water. Many bore waters would probably be improved by being first delivered into a receiving-tank, but, so far as the Moree Farm is concerned, all the crops there have been grown by the warm water direct from the bore-head. A cooling reservoir is provided on the highest part of the farm, but it has not been used very much at present. Comparative experiments are now being conducted with both hot and cold water, which may give some definite facts on the subject. During the winter months the warm water is rather an advantage, as it helps to keep up the temperature of the ground, but in summer there is a risk of "scalding," and therefore the watering of tender crops is generally done at night. The term "scalding" is often erroneously applied to bare patches where the crop has, in reality, been "drowned." This so-called scalding effect can be just as easily produced by cold water.

In regard to the small quantity of gas in the water, it is doubtful if it has any effect on plant life, as most of it is dispelled at the valve-opening, and practically none comes in contact with the plants. As the plants absorb their food in a liquid, diluted condition, it is not probable that the gases have any deleterious effect on the roots—if, indeed, they reach them at all.

All writers and practical authorities on irrigation claim that underground drainage is absolutely neces-

sary,* but owing to the distance from railways, and the cost of earthenware pipes, it is not probable that pastoralists will go to the expense. If pipes could be burnt on the spot, there is no doubt that the results would justify the expenditure. Where possible, the homestead orchard and garden should be underdrained, although the Government orchard at Moree has not been so treated.

PERA BORE ARTESIAN IRRIGATION FARM (Near Bourke, New South Wales).

The following is from the last Official Report of the Manager:—

Some splendid crops have been grown, notwithstanding that much of the land sets very hard when water is applied, and is, in every way, very hard to work.

An orchard was laid out about five years ago with many varieties of apricots, peaches, prunes, and citrus trees. The ground was not previously well levelled, and, in consequence, considerable difficulty was experienced in irrigating it. The citrus trees did better than any of the other fruits. Vines also made very good growth and fruit. Oranges do particularly well there, producing good crops of first-class, bright, clean-skinned fruit. Where the bore leaves the ground, the water travels up and along the pipes until it reaches a 200,000-gallon tank. From thence it empties into a flume, which not only delivers it to any

* See "Land Drainage," page 243.

high point on the farm, but distributes it to small channels, which in turn deliver it into small furrows, where it is allowed to soak into the ground. Some of the orange trees are five-year-old Mediterranean Sweets, and have produced very fair crops during the last two years. There are at present growing about 1,700 assorted citrus trees. It has been found that, to keep these trees doing well, they require a mulching of leaves, or manure of any kind, which, to a certain extent, keeps the soil from baking too hard. A crop of wheat just coming into head, and standing about 6 feet high, had one irrigation at time of planting, and one since; but several good showers fell this year, which did away with the necessity of further watering.

A row of Old Man Saltbush five years old is doing so well that we have planted 3½ acres more this year, in the following manner: Immediately after a rain the ground was ploughed up and the plants put in 12 feet apart. The young plants were only about 6 in. high, but did not feel the effect of removal, and I am of opinion that the best time to transplant them is in the spring, and after rain. The young plants may be grown in a seed-bed the previous year, and will be in good condition for transplanting the following spring. By planting them a good distance apart, it gives the plants a good area to feed from, and they will withstand the dry seasons better than when planted too closely. There is also room for grass to grow between, and the stock have the opportunity of eating a little of each.

The method practised in applying water to crops at the Pera Bore is as follows:—

Lucerne.—The ground is generally graded, so that there is a slope from the water channel; if there are no distribution boxes, holes are cut in the channel at different places, and the water allowed to run through them and spread all over the paddock. In some few instances the plot is perfectly level, and water is run on and covers the whole plot. After it has had a good soaking, if there is any water left on the surface, it is drained off to a lower level; *otherwise the standing water would kill the roots if allowed to remain too long.*

Hay Crops are watered in a very similar manner, except that furrows are left from two to four feet apart, to guide the water, and from these it either spreads over the ground or soaks in from one furrow to another, according to the quality of the soil. If the ground is loamy, it soaks from one furrow to another, and if hard the furrows have to be close together, or else the ground must be flooded. In growing maize, sorghum, and millet, it is best to plant them in rows, with a furrow between each row.

Trees and Vines.—For these the water should always be confined to the furrows, and under no consideration should be allowed to flood over the surface or reach the trunks of the trees. Thorough cultivation is absolutely necessary for trees, vines, vegetables, maize, etc., sown in drills wide enough to allow cultivation to be carried on. *With thorough cultivation, and watering only when required, the very best crops can be grown.* Under no consideration should water be slopped on and cultivation neglected. If the slovenly way of *not* doing the work is followed, nothing but failure need be expected.

In growing potatoes under irrigation, they should not be watered after they are coming into bloom, else the tubers will be watery and of little value.

The following are Mr. Guthrie's analyses of the waters at the Moree and Pera Bores:—

GRAINS PER IMPERIAL GALLON.

	Sodium Carbonate	Potassium Carbonate	Calcium Carbonate	Magnesium Carbonate	Sodium Chloride	Iron Oxide and Alumina	Silica	Total Solid Matter Dried.
Moree...	39.259	1.101	.642	.295	7.029	trace	1.456	49.782
Pera ...	33.111	1.225	.849	.402	7.600	.252	1.064	45.076

Analyses made by Mr. C. H. Mingaye and Mr. H. P. White, Government Analysts, of the waters of 53 artesian bores in New South Wales show that 28 of the number give a somewhat higher proportion of the most injurious element, sodium carbonate, per Imperial gallon. The proportion of 39.259 at the Moree Bore is a good deal above the average, some of the bores giving only proportions as low as 8.346, 6.712, and the lowest 5.016.

I have treated this element fully in the chapter on "Alkaline Lands," both natural and irrigated, as it is a subject upon which much ignorance, and its concomitant pessimism, prevails; but the possibility (see "Ocean Outlet and Discharge," page 66) of the artesian waters ultimately becoming much purer, if not absolutely fresh, must not be lost sight of. A case in point is that of the two official analyses of the Moree Bore water. The first, made some years ago, gave 39.259 grains per gallon of sodium carbonate; that recently made gave 34.3 grains per gallon of the salt, which supports the opinion I have ventured to give.

DRAINAGE

LAND DRAINAGE.

The work of the hydraulic engineer is not only to put water on, but to get it out of the land by providing a free outlet for the surplus water after it has fulfilled its purpose in replenishing the soil. It is now an accepted fact that there is a sufficient water supply in the river systems of Australia during wet seasons, and from permanent artesian sources, to bring enormous areas of arid country under successful irrigation, provided systematic methods be adopted to conserve and distribute such supplies.

There are two kinds of irrigation—one natural, following rainfall, and the other artificial, due to conservation of flood-waters, and from artesian supplies and their distribution over the surface of the land. In both cases, if the *full benefit* of the supply is to be availed of, under-drainage must be carried out.

Water is necessary for the proper cultivation of plant growth, but too much of it, unless under an effective system of drainage, is as harmful as too little. It is worse than useless to "flood" lands from irrigation channels, whether from river or artesian sources, unless the surplus water can pass freely away after duly replenishing the soil.

The water from the river systems, after the proposed weirs to conserve it during high floods, with contour channelling, are constructed, will command

great areas of country in which more or less perfect natural drainage by gravitation will obtain; but with artesian supplies the position is generally different. It is much to be regretted that so many of the bores have been treated without any thought whatever of ulterior irrigation from their outflows. As was pointed out many years ago by the writer and others, the bores should have been made, not only with a view to outflow, but also in a commanding position on the property, in order that the water might gravitate to lower levels; moreover, a careful examination should have been made with a view to choosing the most appropriate part of the property as regards subsoil strata and its actual value under irrigation. Considering the enormous quantity of artesian water flowing night and day in this country, of which only a fraction is being used or required for the purposes of stock, while an almost incalculable quantity is still stored in the earth awaiting utilisation, it is evident that, as droughts may set in again at any time, systematic irrigation from artesian sources on a large scale will form a permanent feature in the future economy of the country.

In all probability, drainage of the subsoil will not be required to any great extent in irrigation works from the river supplies, if they be properly carried out, the water being, as a rule, of good quality. This does not, however, apply to some of the artesian supplies. As water is a universal solvent, it dissolves something from every substance with which it comes in contact. Limestone formations, salt beds, or alkaline deposits charge it with mineral matters. The alkaline carbonates are present in excess in some of

the artesian waters, and the application of such waters to the soil tends to form an encrustation which affects the economic use of the land. This can be obviated by efficient drainage, either natural or artificial, so that the water may percolate freely through the soil, not only washing out deleterious matter, but letting fresh water and air in to take its place.

In thorough, systematic drainage of land, Great Britain and Ireland take the foremost place. A recent estimate of the total area of *subsoil pipe-drainage* of Crown and private lands in those countries is not far short of 3,000,000 acres.

The history of the art takes us back to the times of the Romans, but, without attempting to pursue this subject, the fact may be recalled that, about a century and a quarter ago, the only draining generally practised in England consisted of forming the surface of the ground into ridges and furrows, and cutting open trenches by the hedges to carry off some of the superabundant water. The modern art dates principally from the methods instituted in the year 1764 by Joseph Elkington, a Warwickshire farmer, who, happening to drive an auger through the bed of a trench, discovered the existence of a water-bearing stratum beneath, by draining the water from which the surface and subsoil became thoroughly drained. Mr. Smith, of Deanstone, and others, subsequently extended the principle of consulting the texture of the subsoil, and adapted the depth, capacity, and construction of drains to the varieties of texture. With these improvements, the thorough drainage of agricultural land in Great Britain advanced rapidly. The total extent of " wet " lands capable of draining in

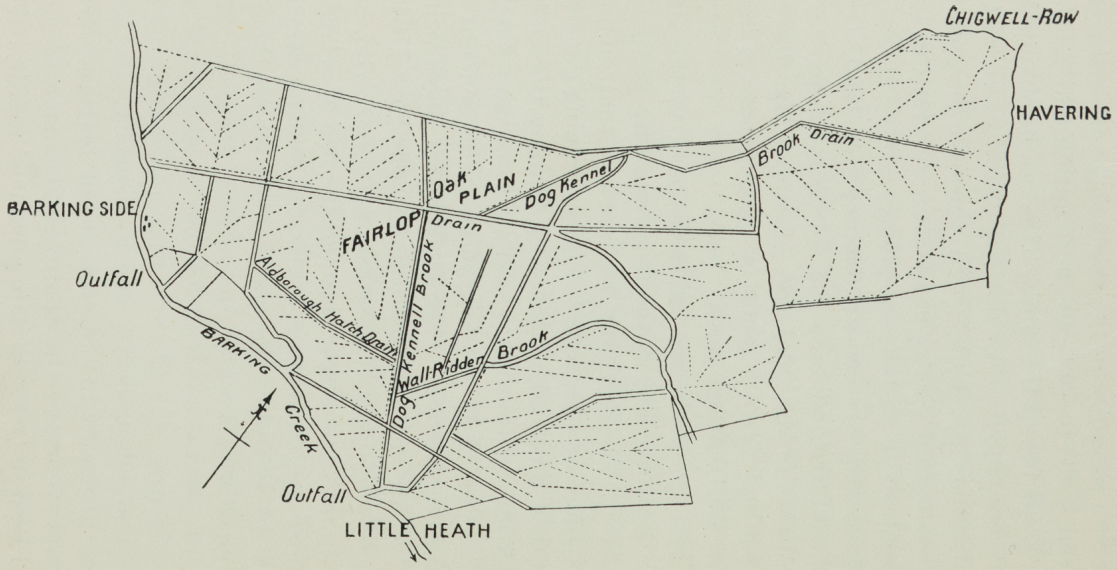


Fig. 56.—Arterial and Subsoil Drainage.

that country have been estimated by Mr. Bailey Denton, C.E., a leading authority, at 22,900,000 acres.

In order to fully and thoroughly treat this part of the subject, and, as there is at present little means of illustrating it by actual work performed in this country, it will be necessary to call upon outside practice for the purpose. The reclamation of Hainault Forest, formerly a Royal forest, in Essex, England, in which I acted as Chief Assistant Engineer under the late R. B. Grantham, M.I.C.E., is an instructive example of the combined application of surface and *subsoil* drainage to a swamp country. The Hainault Crown Property contains about 2,000 acres. It came under the Disafforesting Act of 1861. All the timber, consisting of stunted oak and hornbeam pollards, was first cleared off. The land, in its original state, was covered with a thick growth of underwood, coarse grass, rushes, and weeds, and the greater part of it was a mere swamp. The formation of the ground consists of a level plain (see Fig. 56), part of it known as Fairlop Plain (containing the celebrated "Fairlop Oak," in which King Charles the First hid after his escape from the Battle of Naseby), lying at the foot of a ridge of land sloping towards the south. Another ridge projects into it from the east, and at the foot of the ridges are valleys which bring down the water beyond the limits of the Crown allotment.

The first operation in the reclamation was the making of roads and arterial (open) drains. Some of the roads are parallel to the drains. Material was thus afforded for the formation of the roads, and much severance of land was obviated. There

are three principal valleys, in each of which straight and regular open drains have been made proportioned to the quantity of water it was calculated they would carry off. Into these open drains all the mains of the pipe-drainage, which has been executed over an area of about 2000 acres, have been carried, as well as the surface water of the allotments and lands adjoining. The dotted lines on the plain show the main pipe-drains; smaller pipes lead into these drains, which discharge into the open drains at the points shown. The drains accurately describe the contour profile of the land, the direction being that of the greatest fall. The main outlets are into Barking Creek, a tributary of the River Thames.

The system adopted in thoroughly draining this large district was to have as few open drains as possible; and mains, with large pipes, were extensively used, considerably increasing, of course, the first cost. But the area of land thereby gained for profitable cultivation was increased in proportion, and the labour of tillage largely reduced. Agriculturists neglect the mouths of under-drains if numerous, and consequently it is economy to have as few outlets as possible. The result of this arterial-open drainage, in connection with the underground pipe-drainage, which latter aggregated 615 miles in length, has been that all the rainfall is carried off with the greatest facility. The forest, formerly useless, has become valuable farm land.

In laying out all land drainage, the lowest point of the property must be first ascertained. Open drains must then be made—in number as few as possible—and designed, as regards capacity, accord-

ing to the rainfall of the surrounding catchment areas, with due allowance for evaporation and soakage (both of which are dependent upon the nature of the soil), the surface levels, the intensity of the sun's heat, and drying winds. Actual experiments made by the writer in laying out a drainage scheme on the South Coast of New South Wales show that at least 60 per cent. of the rainfall does not reach, or pass through, a system of open drains within a full week of the time of a heavy rainfall—that is, before pipe-drains have been made; and that evaporation is the ruling element in the result. Evaporation exhausts, during dry weather, the previous soakage water for a limited depth, leaving the deeper stagnant water untouched, and renders the surface soil ready to receive a fresh supply from above. Such are the results of open drains alone; but, when the soil is additionally and thoroughly treated by subsoil drainage, a complete and perfect result is obtained because the foul water is removed from the level of healthy plant-root-growth, and fresh air and water are admitted. In treating lands of a limited area, I am of opinion that there is no real need for open drains at all, and that thorough subsoil drainage is all that is required. The heavy cost of open drains should be transferred to exclusive subsoil draining. On closely-settled farms open drains absorb valuable surface; are an obstacle to farm traffic; necessitate an outlay on bridge crossings; are constantly silting up from broken banks and settlement from flood-waters, or become choked with aquatic vegetation.

With systematic pipe-drainage, the whole subsoil becomes absorbent on each side of the drains, and to a

depth from above which all stagnant water has passed away to the lowest outlet on the property. Open drains intercept and carry off the surplus water which follows the fall of the ground, and, after the floods have subsided, they draw or intercept the subsoil water for a limited distance on either side of them, but they do not draw the bulk of the subsoil water, which lies in the considerable spaces between the drains, forming at least nine-tenths of the total area of the wet land. The water which it is most desirable to get rid of does not, in fact, enter them to any appreciable extent, so that the outlay upon open drains is only, as intimated, partly remunerative. To make it entirely so, and thoroughly to drain the land, recourse must be had to under-drainage.

FARM DRAINAGE.

Soil drainage is the removal, either naturally or by artificial means, of the surplus water from the soil; hence a drained soil is one which is moist, but not saturated with water.

All soils used for the production of the plants most prized by the farmer must possess, in addition to other necessary elements, a certain quantity of water, or they will not yield the largest possible returns to the cultivator. This water is usually termed moisture, and soils in which the proper proportion exists are commonly called "dry soils," to distinguish them from those which contain a surplus of water, called "wet soils." The farmer, therefore, in speaking of a dry soil, does not mean one which is devoid

of water, but one which contains the quantity of moisture best adapted to produce the most desirable growth of his plants; while the term "wet soil" indicates one that contains more water than is needed, which acts in such a way as to prevent plant life from reaching perfection. A perfectly dry soil is dead. It is worthless for producing plants except those which derive their nutriment from the atmosphere alone. A soil which is completely saturated with water will produce nothing but aquatic plants of no value, and hence is worthless for cereals and other valuable products.

The nutriment which plants take from the soil is in liquid form only, it having been prepared by the chemical action of heat and moisture upon the elements present. An excess of moisture reduces the temperature, excludes the air, and dilutes the plant food, thus retarding, or entirely stopping, the growth of the plant as effectually as is done when the soil is dry.

Texture of Soils, and its Relation to their Drainage.—Soil is composed of a large number of exceedingly small particles of various shapes, which touch each other, or, more strictly speaking, have a film of water or air between the contiguous parts. Experiments are being made to determine how fine these particles are, and just how much empty space there is in a given volume of soil; but this is not material in this article. It suffices to say that these particles vary in size in different soils. Those composed largely of sand have much larger particles than those in which stiff clay or fine loam predominates. As these particles cannot lie together so as to form a solid,

there is a large volume of empty space, which, in an average soil, equals one-half its volume. By that law of physics known as surface tension—that is, the attraction which the surface of a solid has for a liquid—each particle of soil holds a film of water over its entire surface, and thus provides a supply of this material for the root of the plant. When the quantity of water in the soil is greater than is required to supply that which is held by surface tension, the remaining space is filled, and the soil is said to be saturated. If we provide an outlet for the water, the surplus will pass off by force of gravity, leaving only the film which is held by surface tension, and which furnishes the desired moisture. This is from 15 to 50 per cent. of all the water which a soil will hold which will not pass off as drainage, but will remain to contribute to the growth of plants, and will aid further in the preparation of additional plant food. This recurring moisture moves through the soil, even against gravity, by the force of capillary attraction or surface tension, as shown in the rise of liquids in small tubes and between surfaces of solids which are close together. This force tends to distribute and equalise moisture in the soil. Where the principal supply is above, or in the surface layers, it is drawn downwards; where it is below, it is drawn upwards.

As before stated, about 50 per cent. of the volume of ordinary soils is space, and is always filled with water or air, or both. The individual spaces are larger or smaller according as the soil grains are more or less minute. A close clay soil, and a very coarse sandy soil, will illustrate the extreme differences.

The fine grains present more surface in a given volume, and hence will retain the greater quantity of moisture. The coarser soils will permit a much freer percolation of water, and hence quicker drainage than fine ones, since the closeness of the particles in the latter offers an additional resistance to the passage of water by gravity through the soil.

It will be seen from this brief explanation that in well-watered localities drainage is the regulation of soil and moisture, and, as such, is necessary in many soils.

Natural and Artificial Drainage.—Some of the best-drained soils are so by nature. They are underlaid with a stratum of material which gives free egress to surplus water and are composed of elements which respond readily to the efforts of the cultivator. On the other hand, there are soils just as rich in natural fertility which are unproductive because, under all ordinary circumstances, they contain too much water. Their location is such that they are saturated beyond the point required for profitable plant growth. It is only when the rainfall reaches a minimum quantity, and the climatic conditions are most favourable, that such soils yield the desired harvest, and profitable return for the labour of the cultivator. Such soils should be artificially drained. This alone will develop their fertility and make them profitable to their owners. Whether the excess of soil water comes from rainfall direct or from seepage of soils which occupy a higher level, the surplus must be removed before the soil will be in proper condition for plant growth.

Surface Drainage and Under Drainage.—Surface

drainage is the removal of water from the land before it enters the soil—or, at least, before it penetrates further than the surface layer. This is effected by open surface channels. Under-drainage removes surplus water by taking it downward through the soil, and away from it by means of natural or artificial channels within the soil. This principle should stand out clearly in all drainage operations—viz., that *all surplus water should be removed by passing it downward through the soil, and not over its surface.* The advantage of so doing may be briefly stated as follows:—

The surface soil is retained entire, instead of the finest and most fertile parts being carried off with every considerable rainfall.

Any manure or other fertiliser deposited upon the soil is carried into it with the water as it percolates downward from the surface, and so becomes thoroughly incorporated with the soil.

Rain water itself is a valuable fertiliser and solvent on reaching the soil by dissolving and preparing soil material for the nutrition of plant life.

The soil is prepared, and is at all times in readiness during the growing season for the growth of plants, such growth not being hindered by stagnant water or saturated soil.

In the case of stiff clays, the soil is made more porous, open, and friable, and roots penetrate deeper than they do into undrained soils.

The effects of drought are diminished, as has been found by experience, owing to the enlarged and deepened soil bed, and to the perfect condition of the surface for preventing undue evaporation of moisture.

It ends in making new soil out of the unprepared elements, since it permits a freer entrance of air and atmospheric heat, which disintegrate soil material hitherto unavailable for the use of plants.

Lands Requiring Drainage.—All farm crops require a drained soil, but this does not necessarily mean that they need artificial drainage. When, however, natural watercourses are insufficient to remove the surface water, they must be improved by artificial means. Where the subsoil is close, and permits the water to pass through it slowly, or not at all, thereby keeping the soil saturated for several days after every rainfall, we must resort to artificial drainage. Soils known as "spouty"—that is, soils kept saturated by water which percolates through from higher levels—should be relieved by under-drainage.

Pipe-Drainage.—Although the trenches may be filled at the bottom with stones, wood cuttings, or even dried peat, it has been clearly established that the best method, and the cheapest in the long run, of under-draining is by means of well-burned, circular clay pipes, 1 foot long, laid on the "herring-bone" system in equidistant parallel lines, and running into a main drain of larger pipes which discharge into the open drains or a creek. Any water which finds its way into the pipes will thus be carried by gravity away from the soil. Water enters the line of pipes through the opening left between the ends, or "joints," as they are called. The ends of the pipes should be placed close together, in order to prevent the soil from entering, yet not so close as to prevent the entrance of the water. The action of a pipe-drain in removing the surplus water from the soil is as

follows:—The drain being surrounded by soil, the spaces of which are filled with free water, water flows by gravity through the crevices between the ends of the pipes, and passes off more or less rapidly, according to the grade upon which the line is laid. Other water of the soil takes the place of that which was removed, the water of saturation gradually passing away from the surface downward, that near the level of the drain being the last to pass off. Water moves downwards, and laterally towards the drain. The lateral distance to which the drain will relieve the soil of water is governed by the resistance that the soil particles offer to the flow of water between them. This process does not leave a soil without moisture, as it still retains all the water held by surface tension. Nevertheless the drains receive water from points below the level of the drain.

In this process, it is interesting to note that, while, to begin with, the soil is fully saturated, no stagnant water remains. There is a continuous movement, the upper water taking the place of the lower as it is removed.

In order to secure efficient drainage, the separate lines of pipe must be placed sufficiently near to each other for the effect of one line to reach that of the other, thereby bringing all the soil within the active range of the drains.

What should Govern the Distance apart and Depth of Under-Drains.—The answer to this question depends upon the character and general structure of the soil. Because a certain depth and distance apart has given satisfactory results in one locality, and with one kind of soil, it does not follow, as is sometimes supposed, that the same treatment will give equally

good results in soils of a different character. The readiness and rapidity with which soils drain depend upon the fineness and compactness of the soil particles composing them. If the material to be drained were coarse sand, a single drain might have an effect for several hundred feet on each side of it, whereas, if it were dense clay of certain kinds, the effect of the drain would reach perhaps only 15 feet on each side. Hence it follows that only close observation will furnish the means of determining the lateral distance apart at which it is proper to place drains. Dig a hole in the ground when the soil is saturated, and observe how rapidly the water fills it. Note the effect which any newly-dug open ditch, or natural drain, has upon the adjacent soil. If these fill very slowly, the drains must be placed somewhat near—perhaps not more than 30 or 40 feet apart. On the other hand, drains may be placed 50, 80, 100, or even 200 feet apart in some soils, and the effect be all that is desired.

Kind of Pipe.—The pipes used should be circular in shape, straight, and, above all, well burned. They need not be vitrified to be lasting; but, whatever kind of clay is used in making them, every particle should be completely burned. The pipe is then indestructible in earth or water. The poorly-burned may be readily distinguished by their colour, and by their dull ring when struck with a piece of steel.

Size of Pipes to be Used—Drainage sometimes fails, not because pipes are too small, but because they are not located or laid properly.

Necessary Considerations.—First, what depth of water per acre it will be necessary to remove from the land in a given time—say, 24 hours. Second, how

rapidly the water will be brought to the main drains. Third, what surface drainage the tract has that will be available for carrying more than the ordinary rain storms. Considering these matters, what should be the size of the main drains, having regard to their grades?

First Question.—There are times when the ordinary rainfall will be taken up by the soil. At other times, when the rainfall is frequent and heavy, and the soil becomes filled with water, it may be necessary to remove a large part of what falls in 24 hours. There are times when the rainfall is so heavy that the water cannot pass through the soil fast enough, even if the drains are sufficiently large to admit of it, but a part must run off the surface by its depressions and channels, and these it is always well to provide.

If the main drains have the capacity to remove one-half inch in depth of water from the entire tract in 24 hours, they afford what may be regarded as good farm drainage; for even one-fourth, or one-third, of an inch in that time is the limit of the capacity of many of the drains in well-improved alluvial soils. The soil is a great reservoir, and will hold from 25 to 50 per cent. of its volume of water. In localities where no advantage can be taken of surface flow for relief in times of very heavy rainfall, the mains should be so constructed as to carry off one inch in 24 hours.

For lateral drains, no smaller than 3-inch pipes should be used; and, for open soils, where the lines may be placed 100 feet or more apart, no smaller than 4-inch pipes should be used. The following tables determine the number of acres which a pipe of given diameter and per cent. of grade will drain when used

as an outlet. They are based upon Knutter's formula, and are applicable to main drains well laid, where the water is supplied to them by sub-mains and laterals.

Table 1 gives the discharge in cubic feet per second for sizes of pipes from 4 in. to 20 in. in diameter, computed on a grade of 1 per cent., or 1 foot per 100. Table 2 gives the square root of grades from 0.04 foot per 100 feet to 1 foot per 100 feet.

TABLE 1.

Diameter of Pipe in inches.	Discharge in c.ft. per second.	Diameter of Pipe in inches.	Discharge in c.ft. per second.
4	0.16	12	3.40
6	.49	15	6 29
8	1.11	18	10.37
9	1.53	20	13.85
10	2.05	...	...

TABLE 2.

GRADES PER 100 FT., AND THEIR SQUARE ROOTS.

Grade per 100 ft in feet.	Grade in inches (approximated)	Square root of grade.	Grade per 100 ft. in feet.	Grade in inches (approximated)	Square root of grade.
0.04	$\frac{1}{2}$	0.200	0.40	$4\frac{3}{4}$	0.632
.05	$\frac{5}{8}$	.224	.45	$5\frac{3}{8}$	.671
.06	$\frac{3}{4}$	.245	.50	6	.707
.08	$\frac{7}{8}$	.283	.55	$6\frac{5}{8}$	.742
.09	1	.300	.60	$7\frac{1}{8}$	.775
.10	$1\frac{1}{8}$	.316	.65	$7\frac{3}{4}$	.806
.12	$1\frac{1}{2}$	.346	.70	$8\frac{3}{8}$	.837
.14	$1\frac{3}{4}$	.374	.75	9	.866
.16	2	.400	.80	$9\frac{5}{8}$	.894
.18	$2\frac{1}{4}$	.424	.85	$10\frac{1}{4}$	.922
.20	$2\frac{1}{2}$	.447	.90	$10\frac{3}{4}$	.949
.25	3	.500	.95	$11\frac{1}{4}$	.975
.30	$3\frac{5}{8}$	.548	1.00	12	1.000
.35	$4\frac{1}{4}$	.592	...	...	...

To determine the number of acres that a pipe main of given size and grade will drain, multiply the discharge of the pipes, according to size, as given in Table 1, by the square root of the grade upon which it is proposed to lay the main, as found in Table 2. When it is desired that the main shall carry 1 inch in depth per acre in 24 hours, multiply the result by 24; if one-half inch, multiply by 48; if one-fourth inch, multiply by 96.

Example.—How many acres will a 12-inch main drain when laid upon a grade of 2 inches per 100 feet, using the half-inch standard? From Table 1, a 12-inch pipe on a 1 per cent. grade is found to discharge 3.40 cubic feet per second. From Table 2, the square root of 0.16 foot, or 2 inches, is ascertained to be .400 foot; $3.40 \times .400 \times 48 = 65.28$ acres. The same, laid on a grade of 3 inches per 100 feet=81.6 acres. For most of the open soils the one-fourth-inch standard is used in practice, and is attended with good results. This is where drainage water is taken from the surface as distributed by lateral drains into the main, and not permitted to run over the surface until it accumulates in a few places, and thence finds its way into the drain.

In addition to the use of the tables for determining the size of the drains, good judgment must be used in the application of the results. The tract under consideration may have such surface water topography that the under-drains may be called upon to take the drainage of a much larger tract than if the land were nearly level. By reason of the surface slope and drainage, a main may be required to receive the drainage of 20 acres instead of 10 acres, as

would appear at a casual glance. It is important to take into account, also, all the facilities for natural drainage, when one undertakes to drain land by pipes. Too-large pipes involve an expense without adequate return, while those which are too small may entail an annual loss that will soon equal the amount that was apparently saved in the purchase. The proper adjustment of size to the grade upon which the lines are to be laid is important both for economy and efficiency. Where large tracts are drained, some surface relief drains should be provided against excessive rainfall, in order to keep the expense of the main under-drains within the limits of paying returns. A few computations based upon the tables will show very clearly the comparative capacity of drains of a given size laid upon different grades.

How to Locate Drains.—To begin, there must be an outlet available for the system of under-drains it is proposed to construct. This, as will be readily understood, is indispensable. A farm may be sometimes thoroughly drained by simply laying pipes in those parts which are uniformly too wet for profitable cultivation. This is on the theory that the other parts have sufficient natural drainage. In such cases, main lines should be located in the course of natural surface flow, with due regard also to straight courses. Branch lines should follow the same general law. This does not, of course, mean that all the curves and crooks, which are always found in natural depressions, should be followed; straight courses, joined by curves, should mark the lines of the drains.

Land which requires drainage always lies in districts of greater or lesser size, each district or section

having one point to which all the drainage must finally come. The general districts are again divided into sub-districts, each having its outlet within the limits of the general district. The boundaries of these sections should first be determined, and the plans so made that when the drainage work is completed the entire tract will have been provided for. A failure to do this is a fruitful source of disappointment in the drainage work. Locate the main drain in the natural depression, with sub-mains at such points as will furnish outlets of tributary sections. These are the arteries, as it were, of the whole system. This work may be carried out in two different ways. The first is to locate branch lines so as to reach those points of the tract which seem to require drainage, such as hollows, lagoons, and swampy patches, without special regard to systematic work. This is called random field drainage. The second is to supplement the primary network by constructing laterals parallel to each other at a uniform and equal distance apart, according to the requirements of the particular soil, on the theory that every part of the field requires equal drainage.

The most economical system for thorough drainage is that of parallel lines of a good length. This will be readily acknowledged from the fact that, wherever one drain joins another, the tract in the vicinity of the junction has two drains acting upon it instead of one; in other words, it is doubly drained. The laterals should, as a rule, be laid up and down the slope, and not across it, as advocated by many. It will doubtless seem incredible to those who find it necessary to place drains only 40 feet apart that other

soils may be drained as thoroughly with parallel lines 100 or even 200 feet apart. In the latter case however, the pipes *should not be less than 4 or 5 in. in diameter.*

Surveys and Grades.—Whatever may be said to the contrary, it remains a fact that, in order to get the best results in a system of drainage, the work should be laid out with a levelling instrument, and executed in accordance therewith. No one can be relied upon to guess a grade correctly, nor can anyone arrange a system of grades with economy, and at the same time get the best possible work out of the system, without first knowing the facts as determined by the level in the hands of one who is able to use it. The drainage engineer will stake out the lines, adjust the grades, and put the work in such shape that it can be executed with precision, either by contract or day labour. The result of the work can be predicted with reasonable certainty before a ditch is opened. Where there are tracts of level land, or of land so nearly level that it is only by the most accurate work with instruments that it can be drained successfully, the services of a drainage engineer are absolutely indispensable.

The light grades upon which lines may be laid with satisfactory results are a surprise to many—indeed they were regarded as entirely impracticable until the experience of recent years proved the contrary. Lines of drain-pipes laid on a grade as low as one-half inch per 100 feet will perform drainage successfully provided the lines are not too long; while lines laid on grades of from 1 to 2 inches per 100 feet may be counted by the hundreds of miles,

and their successful operation attested by thousands of acres of cultivated lands.

Digging and Grading Trench.—The trench should be started on the surface by a line, and should be clean-cut and straight. Any crook made at the surface will be greater when the bottom is reached. If a survey has been made, the lines should be drawn about 8 inches to one side of, and parallel with, the line of grade stakes. It is assumed that these stakes have been set in a true line, 50 to 100 feet apart, and that cuts from the top of each stake to the grade line of the ditch have been furnished to the workman, or have been marked upon the guides which denote the position of the grade stakes.

The digging-tools which are necessary in alluvial soils are as follows:—A ditching spade, with blade 15 or 20 in. long; a round-pointed shovel, with long handle; and a grading-scoop of the "pull" pattern. In light, mucky soils, a muck-spade, which is a three-tined fork, with a steel cutting-edge like a spade, can be used with profit. Straight ditches and neat work should be insisted upon. In changing line, it should be done with an easy curve. When a lateral drain joins another, it should form an angle of about 30 degrees with it. The most essential thing about a trench for a pipe-drain is the finish and grade of the bottom. When only light grades are available, the lines should be staked out and levelled as before indicated. Many farmers have drained successfully where the fall was 3 feet or more per 100 feet, because it was almost impossible to grade the line so that it did not have fall, and because the fields were small. Such men frequently advise freely against having the

work laid out by an engineer, and the grades carefully computed.

Open Drains.—These should be located with care, following the course of natural drainage, or as near as may be, with due regard to straight courses. The depth of such ditches should ordinarily be not less than 6 feet, with a width on the bottom of 4 feet, where the grade is 1 foot in a thousand or less. If the grade is much greater—say, 3 inches or more per 100 feet—the bottom may be made as narrow as desired.

The side slopes, in loam or clay soils, may be at an angle of 45 degrees, or 1 to 1; where loose and sandy, 2 feet horizontal to 1 foot vertical, or 2 to 1.

As a large amount of preparatory work is required in building a railway in order to secure a place on which to lay the two steel rails properly, so it is in drainage; the ditches, the trenches, and all preparatory work are for the sole purpose of laying lines of pipes in the soil in such a way as to take away the surplus water. The importance of this work merits the care enjoined in carrying out the details, since drainage is a permanent improvement, and, if the work is well done, will need no repairs or reconstruction, but will yield an ample annual return on the investment.

APPENDIX

MECHANICAL POWER DERIVABLE FROM ARTESIAN BORES.

The value of artesian water for irrigation purposes does not by any means exhaust the benefits derivable from the bores. Over the artesian areas of New South Wales and Queensland alone, amounting to 528,000 square miles, it is admissible to predict a great increase in the number of bores and a much larger outflow of water. As the natural rainfall is thus augmented by an increased water supply, settlement will proportionately increase, and with it a greater demand for labour-saving appliances to meet the various requirements of station and farm.

In New South Wales and Queensland, for instance, there are 897 artesian bores running night and day, and, according to careful scientific calculations of the capacity of absorption of the average rainfall by the water-bearing rocks, they may be increased, as heretofore shown, fortyfold. The bores are all running under well-known laws that govern the movement and pressure of water. That pressure may be utilised in the simplest, most economical, and effective manner for work now done by the more costly and cumbersome modes of steam and horse-power.

In a recent Report to the Agricultural Department, U.S.A., of the artesian and underflow investigation, is the following:—

"In no portion of the country has there been a grander development of artesian wells than in the past five years in the Grand and Black Prairies regions of Texas. At numerous places throughout its extent magnificent flows of water have been secured, and what ten years ago was in many places a poorly-watered district now abounds with magnificent artesian wells, which supply water to cities and farms in quantities large enough to make new industries possible, besides furnishing water to irrigate many thousands of acres. The wells vary in depth up to 2,000 feet. They also vary in volume of flow from less than a gallon a minute to a thousand, and in pressure from nothing to a maximum. The industrial uses to which these waters are put are many. At Waco, hundreds of sewing-machines in clothing factories, electric motors, wood-working machinery, and other small industries are run by the pressure of wells—without wasting the water—by the use of the small and powerful Californian wheels. When the high cost of fuel in Texas is considered, this use of artesian water becomes a most important factor."

These bore pressures are exceptionally great, and are equivalent to those of very high heads of falling water—a source of pressure, as applied to turbines or water-motors, much in request of late in Europe and America for working ordinary machinery, and for the generation of electricity for lighting, for locomotive, and for manufacturing purposes.

The use of water for the purposes of power dates back to the early centuries, and, even with the crude and primitive means then available, was made to subserve many useful purposes. It is, however, only

within a comparatively short time that it has come to be recognised as the most practicable and potent of all the elemental forces, destined, in the near future, to do a large part in the world's work. The practice, which has so long prevailed, of appropriating only the larger streams, with low heads, allowing the higher lands to go to waste, is attended with so many difficulties and such expense, as to make a power so obtained often of questionable expediency. The old style of huge water-wheels, working by a low head, but great volume of water, has had its day. The modern turbine offers so many advantages for the general utilisation of all these sources of energy, that streams or waterways favourably situated for power purposes are now being eagerly sought for and appropriated. By its use the entire force, or pressure, from artesian flows obtainable can be made available for all industrial purposes, with a greatly reduced cost, wider range of application, and fuller adaptation to varying requirements, than has before been realised. Nothing in a mechanical way has so signally and quickly proved its own usefulness, as well as its right to the first place in hydraulic-power appliances. Every stream or waterfall, and every bore outflow, is a mine of energy that, by means of this most simple appliance, can be converted directly into useful effect, with almost entire absence of machinery, and made available for any desired purpose, with a high degree of efficiency and comparatively small outlay.

The following bore pressures (which may be taken as representative ones) are from the New South Wales Government Report (1905), the other calcu-

lations being made by myself. It will be seen that bore pressures are of a very high value, as shown by the equivalent pressures from the high heads of falling water.

	Pressure lbs. per sq. inch.	Equivalent Head in feet of falling water.	Effective Horse-power per Pelton wheel 2 feet diameter.
Belalie ...	187	430	67
Engonia	165	380	56
Gil Gil ...	101	230	27
Pilliga ...	109	250	30
Tooloora	126	290	37
Careunga	120	280	35
Oreel ...	190	440	69

It will be seen from the above table that there are inconsistencies in the pressure, as there are in the flows, from artesian bores. It is generally, but erroneously, thought that the greater the pressure the higher the water rises above the surface, and that so in proportion is the flow greater. This is not the case. The discharge depends upon three factors: (1) the pressure under which the flow takes place; (2) the depth, diameter, and conditions of the bore itself; and (3) the nature and character of the stratum in which the flow is obtained. The ascertaining of (1) is an easy matter; (2) is, of course, known in the sinking of the bore; but (3) cannot be directly known. For instance, the flow from a thick seam of low porosity might be equivalent to a thinner seam of greater porosity. A bore with a very low flow—say, 30,000 gallons per diem—when closed might indicate a pressure of 150 lbs. to the square inch, and, owing to the low porosity of the water-bearing stratum, which must certainly control the volume discharged, might take considerable time to

reach this pressure. Another bore might have a much greater flow—say, 1,000,000 gallons—but, owing to the high porosity of the stratum, and a constantly free flow when closed, show a pressure of only 50 lbs. to the square inch. Take, for example, two bores of equal diameter and pressure, but with different thicknesses of water-bearing stratum, of equal porosity; it is evident that the bore which penetrates to the thicker stratum must have the greater discharge. With variations, subject to conditions, there is a workable pressure from all flowing bores.

Where power is to be derived from the high pressure of artesian bores, or an extremely high fall, the use of the ordinary impulse and reaction turbine is rendered impossible—the one because of the enormous stresses which would be set up in the machinery; the other because of the prohibitively high speed which would be developed. With such bore pressure, or falls, an engine of the simplest construction is desirable, and one in which a reasonably high speed is obtained without undue strain on the working parts. Such a form of engine is found in what is known as the Pelton Wheel, if this be intelligently designed. A general view of one form of this wheel, which has found extensive use in the artesian and mountainous districts of North and South America, is shown in Fig 57. The engine consists essentially of a stout wheel, upon the periphery of which a number of specially shaped buckets, or vanes, are secured. The wheel is rotated by the impulse of the rapidly-moving jets, working tangentially against the lowermost vanes, and the power developed is conveyed through the shaft. The power is regulated by a

sliding valve, or sluice, behind the nozzle. The action of the vane, or bucket, on the wheel is to divide

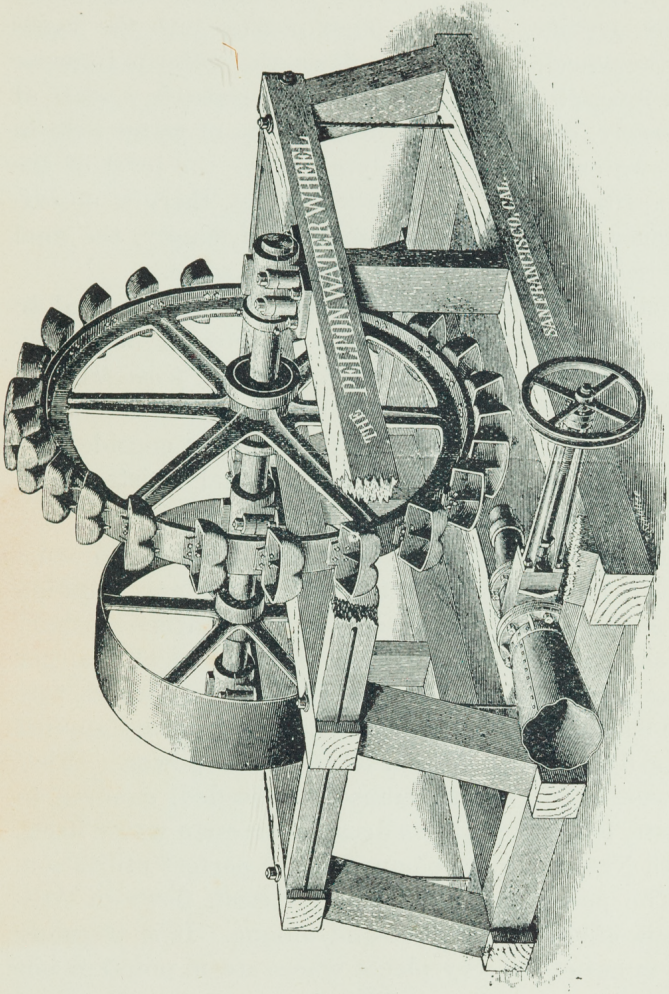


Fig. 57.—Standard Wheel mounted on wood frame, with housing removed.

the jet into two equal parts, each of which glides over the curved surface of the vane, and is deflected back-

ward until it is discharged from the wheel with practically no velocity.

In falling water, the water, in a state of pressure from gravity, is led through nozzles into the vanes of the wheel. In artesian flows, the water is likewise led through nozzles into the vanes—also in a state of pressure, due to gravity of the body of water held in the water-bearing rocks lying above the level of the bore site; so that, in practical effect, there is no difference between the two sources of supply, the final application being, in both cases, the same.

This form of water-motor is specially adapted to utilise the pressure-power from artesian bores, because the power can be applied *direct from the bore itself*, whereas falling water has, in most cases, to be led from its head source to the wheel, a considerable loss of power accruing from frictional resistance inside the piping or fluming.

Taking New South Wales and Queensland combined, there are, as stated, 897 bores now running in these two States. Twenty-eight of them—officially measured— give an average pressure of 82 lbs. per square inch (equal to a 190-ft. head), at which rate the bores now running would give, in pressure applied to a 3-ft. Pelton Wheel, 39,468 horse-power. That power is now mostly unused, unheeded, running to waste, but it appeals, as does the artesian water itself, with Nature's mute eloquence, for perfect utilisation.

The power derivable from artesian flows in Australia is both ubiquitous and unique. It is cropping up in out-of-the-way places where steam power is not payable, and ordinary falling-water power is out of the question. The power is direct, and one of the

most economical conceivable. To meet the numberless mechanical operations of the station or farm, and for electric lighting—a small dynamo and wheel combined being procurable—it is most desirable. The power being free from working expenses in its production, and the cost being extremely moderate, should ensure its extensive use in the future.

A DEEP BORE.

SYDNEY, Thursday.

The Government artesian bore at Boronga, 60 miles north-west of Moree, has been completed. The depth is 4340 feet, which is a record for this State. The water is running at the rate of 1,500,000 gallons daily.

EXTRA RESULTS INCIDENTAL TO BORING FOR WATER.

At the Roma Government Bore, Queensland, a remarkable result accrued. When No. 2 bore had reached a depth of 3,431 feet, yielding 325,940 gallons per diem, sufficient to furnish the population of Roma—namely, 2,000—with 162 gallons per head per day, the local authorities deemed this volume insufficient; and, as the boring was still believed to be in water-bearing strata, it was decided to continue sinking to a depth of 4,000 feet. Thereupon boring was continued; and, at a depth of between 3,669 and 3,693 feet natural gas was tapped in open, sandy, grey-coloured shale; but as the gas continued to increase in volume and pressure, further boring became almost an impossibility with the means at hand, and boring was finally stopped at the depth of 3,709 feet. Subsequently successful arrangements were made for separating the gas from the water, and at present each flows from a separate tube, the result being excellent water from one, and gas and a small quantity of water from the other. The water from the bore has a temperature of 104 degs. Fah., and the flow now measures 158,900* gallons per day, sufficient to supply a population of 5,297 persons with an allowance of 30 gallons per head per diem, which, for a non-manufacturing town, is liberal, even in a hot climate like that of Roma. The mixture of gas

* This is exclusive of 39,411 gallons per diem of a temperature of 113 degs. Fah., which flows with the gas.

and water coming up from the lower depths spouted intermittently from the inner casings to heights varying from 15 to 30 feet above the surface; and, on opening the gas orifice, after it had been partially closed for about two hours, the gas and water spurted, in a horizontal direction, to a distance of about 100 feet. The gas is one of the numerous compounds of the hydro-carbons, so often met with in coal measures. With an ordinary burner it gives a light yellowish flame. A chemical analysis and photometric measurements of this gas in its natural condition show that the outflow amounts to 70,000 cubic feet per diem, and that it is an excellent illuminant of 24-candle-power—some 50 per cent. better than the London 16-candle standard. Gas works have since been established, and the town fully supplied with gas—as it is, by a similar reticulation, with water.

The "luck of Roma" is not all told. The water from the bore had a strong odour of kerosene—the analyses, however, showed the composition of the water to be similar to that of other bores, the principal solids being carbonate and chloride of sodium. The first running of the water was often oily—an indication of the existence of petroleum. The flow of gas and the geological conditions being similar to those of other parts of the world where the petroleum industry is established, such as Pennsylvania and Canada, induced the formation of a company, which made a bore outside the town, and have recently obtained the pure "rock oil," or petroleum, in considerable quantities. "At the Ruthven Bore, 192 miles from Charleville, Queensland, at a depth of 3,000 feet, blue shale was gone through, and then a great quantity

of natural gas was obtained. Between 3,000 feet and 3,600 feet several seams of coal were passed through; when 4,060 feet were reached, the formation changed to dark sand, and rock oil, or petroleum, in no small quantity was obtained. It was just under this that the second supply of water was struck.''*

There are similar indications in the bores of New South Wales. A distinguishing feature of the artesian water obtained from them is a strong odour of sulphuretted hydrogen, which speedily passes off after exposure to the atmosphere. Mr. W. M. Hamlet, Government Analyst, who has visited a number of the bores, was, however, after subjecting them to careful tests, unable to obtain any reaction for the gas, or for free sulphuric acid; and, with the exception of Ballimore Bore, near Dubbo, which yielded a flow of carbonated water, none of the artesian bores in New South Wales are known to evolve free carbon dioxide. There is therefore, at present, no evidence to show that gas pressure plays a part in the rise of the artesian water of New South Wales.

A feat not less marvellous than the harnessing of Niagara has just been accomplished in Idaho, one of the new American States. A town of 15,000 inhabitants has been warmed throughout by hot water from the bowels of the earth. Boise, the town in question, is what is known as a "blizzard city." It is subject to frequent snow-storms and blizzards, and has a winter temperature of 30 degs. below zero. Hitherto the cost of artificial heat has been a serious item to the inhabitants. Recently they heard that the State

* "Queensland Mining Journal," Jan., 1905.

Geologist of Pennsylvania, Mr. H. C. Denning, had determined that the earth's crust was very thin in their region, and might be tapped for hot water and steam, for the practical heating of stoves and residences. To some of the wiseacres in Boise the idea seemed to be nonsense so far as utility was concerned.* But several leading men took the idea seriously, made a few bores, and Boise was kept warm last winter by hot water and steam from the bowels of the earth. Some of the warm water is used for watering the streets, with the result that the grass and trees in the city are in full verdure in March. The deepest of the bores is 2,000 feet. Tanks receive the outflow of the group of borings, and from those tanks the hot water and steam are forced through pipe-lines to all the public buildings, and to shops and private dwellings.

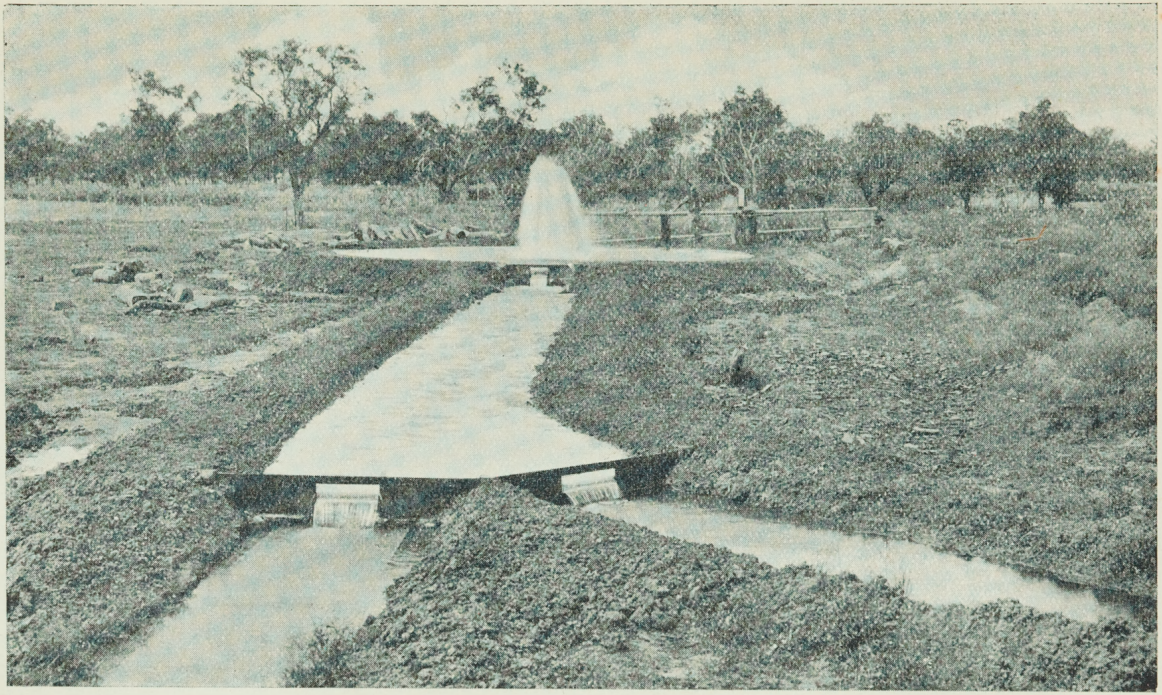
At Dagworth Station, North Queensland, the temperature of the bore water is 197 degs. Fah. Half a mile below the bore an egg may be boiled in the stream, and the water is perfectly fresh and good. At Woolerina Bore the wool-washing is performed ten miles down the creek from the point at which the bore water enters it. The water is hot for nearly a mile and a half from the bore.

* Similar pessimism and apathy, as is well known, existed in Australia in the early days of the movement for artesian supplies.

STATISTICS OF BORING, SUPPLIES, AND DISTRIBUTION.

(From N.S.W. Public Works Report, 1905.)

The number of flowing bores is at public watering-places 55, under the Artesian Wells Act 26, and on improvement leases 50, private bores 157—total 288. The average depth of all the bores is about 1,100 feet. The total daily outflow is about 155,000,000 gallons. The shallowest are on Killara Station, where No. 1 bore at 46 feet gives 9,000 gallons per diem; No. 2, 140 feet, 160,000 gallons; and No. 7, 540 feet, 500,000 gallons per diem. (See "Mound and Mud Springs," page 20.) The deepest is at Dolgelly, Moree district, depth 4,086 feet, flow 682,200 gallons per diem, temperature 130° Fah. The greatest present flows are those at Coorumbia, Lila Springs No. 3, and Lissington Fah., depth 1,757 feet, flow 1,000,000 gallons per diem. The highest temperature is at Elsinora No. 2, 135° Fah., depth 1,757 feet, flow 1,000,000 gallons per diem The highest pressures are at Belalie, 187 lbs., and Oreel, 190 lbs., to the square inch. (See "Mechanical Power from Bores," page 266.) The deepest bore completed during the year was at Euraba, in the Moree district, where a 6-inch hole was carried to a depth of 4,002 feet, which, in regard to diameter, is understood to be a record for Australia, and a notable example of deep well-sinking throughout the world. The flow obtained is approximately 1,000,000 gallons per diem.



Florida Bore, New South Wales, showing Distributing Tank and Diversions.

Besides a great deal of channelling on private stations, drains have been constructed at Brewan and Wyabray, and are now being constructed at Dolgelly, Moree district, and the construction is being vigorously prosecuted at Careunga of channelling for 17½ miles, at Florida 28½ miles, Rowena 34 miles, and Three Corners 5½ miles.

During the year particular attention has been given to the completion of the distributing works necessary to obtain the full benefit from the wells.

Distributing Works.—The works of this nature previously undertaken were to a great extent of a pioneering character; but, in view of the large expenditure involved on works remaining to be completed, some alteration in location and design was found to be necessary.

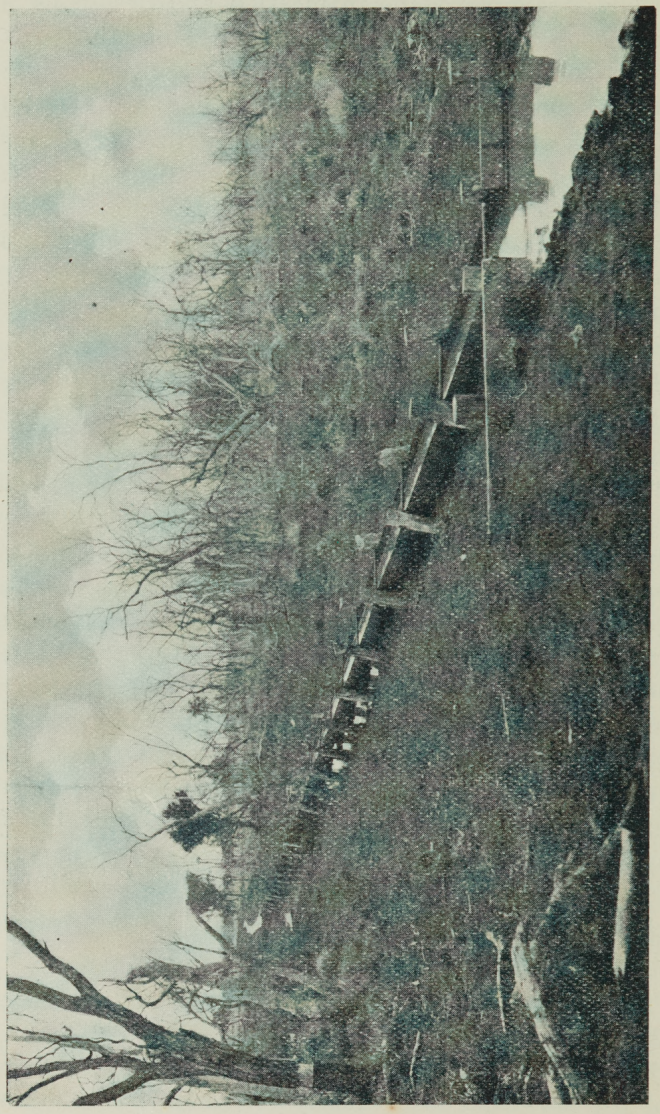
Location.—The previous system of location has been altered, straight lines, with accompanying heavy cuttings and deep embankments, having given place to contoured lines with drains in surface cut, the location, grading, and dimensions of same being entrusted to the engineering surveyors, who, being on the ground, are in a better position to provide works suitable to the requirements of the different districts.

Design.—The alteration in the system of location has rendered possible a type of drain which, being practically all in cut, is not only more serviceable and permanent, but reduces the seepage losses in banked drains; further, the drainage can be constructed with plough and delver or grader, in lieu of the evenly batter slopes, which are in a few weeks trampled out of shape, and have no advantage over the class of work now adopted.

The departures made in location and design have been made under the superintendence of Mr. Percy Allan, M.Inst.C.E., Chief Assistant Engineer, Public Works Department. They have had a material effect on the cost of the works, distributing drains having been completed at the low prices of from £12 15s. to £6 10s. per mile. The high professional status of Mr. Allan is a guarantee that the fullest and best utilisation of the artesian waters will be effected, providing his advice is acted upon.

Iso-Potential Lines.—The height to which the water would rise in the different bores, if casing were carried above the surface, has long since been determined in Queensland and South Australia, and maps showing the iso-potential lines have been published from time to time; but practically little has been done in this State, owing to the large proportion of private bores being seldom provided with closing gear, without which the pressure is unobtainable. Closing valves are now being supplied to the different districts, so that by the time the next report is published it is anticipated this work will have been brought into line with that of the other States. Maps can then be prepared, from which can be determined by inspection the probability as to whether water in a bore at any proposed site will rise above the surface or require pumping—information which will be of very great value to those interested in the western districts.

Geological Survey.—The desirability of obtaining the relation between the rainfall on the intake beds—the source of the artesian supply—and the discharge of the bores has been clearly recognised, and a geo-

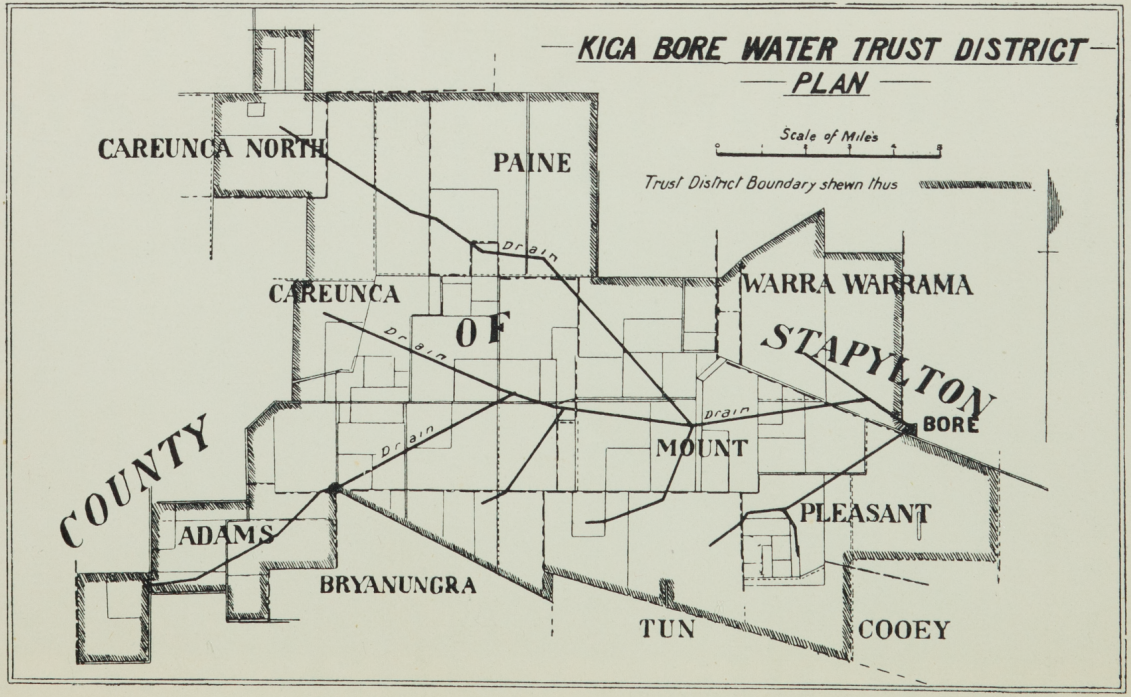


Fluming, Florida Bore Drains.

logical survey of these beds has been undertaken by Mr. E. F. Pittman, the Government Geologist, and the work is now well in hand. A Venturi meter, with diagram apparatus showing a continuous record of discharge, has been installed on the Florida Bore, in the Moree district, which will clearly show the variation occurring in the flow. With the completion of the survey of the intake beds, and the recorded discharge of the different bores, some interesting data will be available, and will permit of some definite conclusion being arrived at as to the time taken for a deficient rainfall on the intake beds to affect the discharge at bores situated many hundreds of miles away, and to reach which the water has to percolate through miles of porous sandstone.

Works under the Artesian Wells Act.—Under the provisions of the Artesian Wells Act, distributing works have been arranged for in connection with Kensington, Milchomi, and Rowena Bores, and the lands benefited will, upon the completion of the works, be assessed by the Local Land Board, such assessment, however, under the Act, being limited to 6 per cent. on the capital cost of the works. During the year the district officers at Bourke and Coonamble appeared before the Local Land Board, and obtained 6 per cent. assessment in connection with Killoween and Haddon Rigg Bores, which, when divided amongst the landholders concerned, amounts to but a few pounds per annum for a permanent running stream passing through the different holdings in the most suitable positions for stock-watering, etc.

The other works completed under this Act are Ginghet, Goangra, and Willie Bores, and the Land



Distribution Channels, Water Trust District.

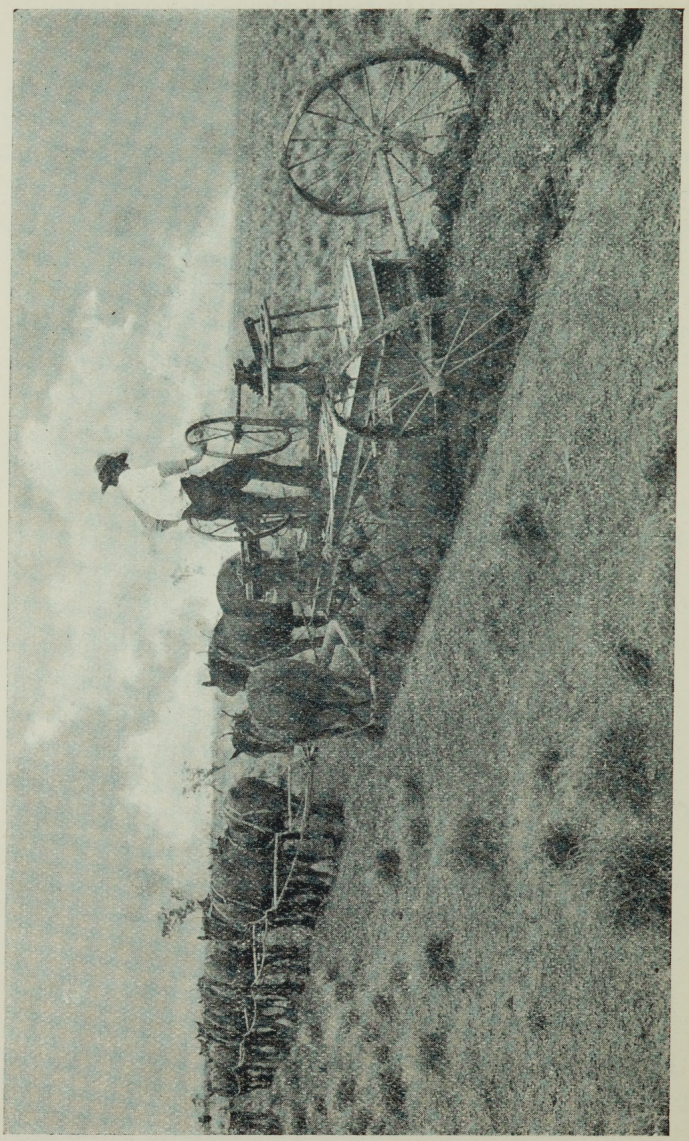
Board is being asked to make the necessary assessment in each case.

Works under Water and Drainage Act.—This Act differs from the Artesian Wells Act, inasmuch as the works, when completed, are handed over to a trust, the elected trustees making an assessment to cover maintenance, 4 per cent. interest and 2 per cent. sinking fund, to liquidate the capital cost of the work at the end of 28 years. Trustees have been elected and works transferred to them in connection with the Three-Corner and Come-by-Chance Bores, and no doubt very much interest will be taken as to the success of financial administration by local trustees.

Under this Act five drainage proposals have been gazetted, whilst action has been taken to form trusts and gazette the proposals in connection with 22 bores, which will ensure a return on the capital outlay and do away with the waste of water which has resulted for some years from the absence of distributing works.

Conclusion.—The policy laid down in connection with artesian bores has been to, in the first instance, provide for stock-watering as much country as possible from each bore, with a view to keeping down the assessment per acre to the lowest limit, it being a matter for the subsequent consideration of the trusts as to whether sufficient rates can be raised to warrant the department in sinking additional bores to permit of irrigation in addition.

In connection with the 28 bores referred to in this Report, provision is being made for 825 miles of distributing drains to water 2,587 square miles of country, the flow from the bores being estimated at 23,000,000 gallons per diem. One of the largest dis-



Meaney and Polder's Grader at work on Florida Drains.

tricts yet dealt with includes an area of 128 square miles, provided with 57 miles of distributing drains, to be kept constantly running with a flow of 684,400 gallons per diem from a bore 4,013 feet deep, the fall from bore to end of district averaging six feet in the mile, *which shows the immense possibility of artesian bores with properly laid out distributing works.*

With the placing of these bore works in a completed state, so as to ensure an equal distribution of the water, it is not anticipated that—with equitable and firm administration—any difficulty will arise in the Government obtaining a 6 per cent. return on the capital outlay, the benefit derived from a permanent running stream of water, seldom more than two miles from the boundary of any holding, being such as to appeal to the settlers and engender a feeling of security, for which they are very willing to pay the small annual charge as an insurance against scarcity of water in times of drought.

CONCLUSION.

This book has been compiled after many years of practical work and study—first in England and America, and then in Victoria, New South Wales, Queensland, and Western Australia; and it is to be hoped that enough information has been given to enable those who have neither the leisure nor inclination to study technical documents or Government reports on the subject, to gain a knowledge of the prominent features and conditions of artesian and river supplies, *and, what is of paramount importance, the proper systematic application of the waters to irrigation.* The conclusions drawn will doubtless be as follows:—

1. That enormous quantities of water may be conserved, during flood seasons, in the Darling-Murray River system, and made available for irrigation over large sections of country.

2. That immense accumulations of water are available, lying in the crust of the earth in the artesian areas (which areas it would not be economically practicable to supply from the Darling River system), and that these, as they are drawn upon for our requirements, will, in all probability, be amply replenished in the future as in the past.

3. That the exposed areas of the outcrops or intakes of the water-bearing rocks are very much greater than was at first supposed, and that an additional supply—previously unthought of—is provided by the rivers and creeks which

cross the outcrops, and which must enormously increase the general subterranean supply, bringing water, as they do, from large independent areas of country. And that it is possible to still further increase the intake by clearing a strip along the upper line of the outcrop down to the bare absorptive rock.

4. That the quantity of water in the gravels of which the channels of our rivers consist, must be very great, and that much of that water passes into the gravels of the underground channels, and finally into the vast porous beds of the Cretaceous and Triassic formations, from which our deep supplies are being obtained.

5. That the artesian supply is a comparatively constant one, not being regulated, as are river supplies, by wet and dry seasons.

6. That reservoirs and channelling supplied with artesian water will not depreciate in value by silting up, as do those supplied by flood waters.

7. That the general fall to the ocean of the water-bearing rocks is so gradual, and the velocity of the flow of water in them so slow, and its volume, spread under enormous areas, so great, that the supply may be considered adequate for a very much greater increased production on the surface, and for its utilisation for irrigation and for the requirements of stock.

8. That, under intelligent, systematic treatment, artesian water may be safely relied upon for

raising crops of all kinds, and that the reported failures in its application, at certain bores, is *traceable to the use of too much water and the lack of proper cultivation and drainage.*

9. *That, in all probability, as the outflow is increased by additional bores, the water will become of a better, if not perfect, quality.*

I may also say, in conclusion, that I have endeavoured to treat this great and vital subject of an increased water supply from artesian and river sources, and its utilisation by irrigation, from the standpoint of a Civil Engineer, whose education, studies, and practice embrace all knowledge bearing upon it. In doing so I may also say that I have had in view the obligation I am under, as an old member of the Institution of Civil Engineers, London, to get at the truth in my profession, and to promulgate it to the best of my ability.

Australia is, without doubt, destined to take a leading position (as she is already a recognised authority) in the art which forms the main subject of this book. Although the country is endowed with unbounded physical wealth and resources, and an incomparable climate, artificial water supply must be called upon to neutralise its one great drawback — periodical droughts—be it by rivers or from its now great established source of supply—artesian wells. Whatever conclusions may be reached as to the need of legislation upon the subject, this may fairly be said: That the facts fully justify an increase upon present expenditures, and demand, because of their weight and importance, a full and serious consideration of the

grave legislative and economic, as well as the hydraulic and other physical problems involved. They vitally concern the present and future administration of a large section of our public domain; they are intimately connected with the industrial security of a considerable and growing population, and with the progress and conservation of our western country.

INDEX

	Page
Absorptive Capacity of Artesian Rocks ...	80
Alkali, Causes of	210
Chemical Treatment	212
Prevention of	211
Remedies for	201
Water-logging	210
Alkali Lands, Chemical Antidotes	204
Effects of Artesian Water	205
Eradication by Vegetable Growth	204
Flooding System ...	203
Formation of	199
Magnesium Sulphate	208
Mulching and Leaching	214
Sodium Carbonate ..	207
Sodium Chloride ...	206
Sodium Sulphate ...	206
Treatment of	198
Waters Carrying Alkali	201
America — Methods of Irrigation	135
Artesian Basin of Australia	8
New South Wales	12
Queensland	34
South Australia ..	52
Western Australia	54
Bores as Affecting Climate	90
Variation in the Amount of Flow from	83
Flows, Multiplication of Bores	76
Formation, Geological Survey of ..	281
Impervious Rocks underlying the Storage Beds ...	31
Artesian—	
Thickness of Porous Beds	29
Intake Beds	28
Machinery	91
Rocks, Absorptive Capacity of	80
Supply, Forecast of the Future of ...	87
Hydraulic Considerations of	87
Potential Resources	77
Scientific Research Necessary	88
Venturi Meter ...	283
Water, Definition of	6
Conditions Governing Rise of	85
Irrigation of Fodder Crops	81
Moree Irrigation Farm	226
Pera Irrigation Farm	239
Potential Resources	77
Results of Irrigation	226
Temperature of ...	69
Variation in Flow of	83
Block System of Irrigation	168
Blythesdale Braystone	26, 40
Boring for Water, Extra Results incidental to	274
Buck Scraper	162
Calyx Drill	96
Canvas Dams.....	164, 173
Capillary Attraction..	252
Cement-lined Distributing Ditch ...	182
Charleville (Ruthven) Bore, Gas and Petroleum at ..	275

	Page
Checks, Flooding in	166
Chemical Treatment of Alkaline Lands	204, 212
Climate as Affected by Bores	90
Irrigation Dependent on	140
Corn Maize	186
Cost of Irrigation with Bore Water	82
Cultivation after Irrigation	184
Desert Sandstone	23
Diamond Drill	95
Discharge from Bores per Venturi Meter	283
Ditch-Making	158
Drainage and Alkali ..	209
Land	250
Evaporation	68,155
Dimensions of Reservoirs, with regard to	157
From Earth	157
Neutralising	158
Extra Results incidental to Boring for Water	274
Charleville (Ruthven) Bore, Gas and Petroleum at ..	275
Indications of Gas and Petroleum in Bores of New South Wales ...	276
Roma Bore, Queensland, Outflow of Water and Gas at	274
Farm Irrigation — Arrangement of ..	189
Drainage	250
Flood Loams and Black Soils	19
Flooding Alkali Lands	203
In Checks	166, 169
Wild	177
Fodder Crop Irrigation	81
Foreign Irrigation	133

	Page
Fruits, Irrigation for	187
Furrow Irrigation of Grain	172
Of Orchard	178
Of Vines	178
Watering	172
Garden Irrigation	170
Gas in Bore	275
Geological Survey of Artesian Formation	281
Ground Water, Rise of, Following Irrigation	192
Intake Beds, Artesian Formation	28
Irrigation, Amount of Water applied ..	135
Block System	168
Buck Scraper	162
Canvas Dams ...	164, 173
Cement-lined Distributing Ditch ...	182
Climate	140
Corn-Maize	186
Cultivation after ...	184
Day and Night	141, 238
Ditch-making	158
Extent of, in other Countries	133
Farm, Arrangement of	189
Flooding in Checks,	166, 169
Fodder Crops	81
Fruits	187
Furrow, of Grain ...	172
Of Orchard	178
Of Vines	178
Garden	170
General Crops	166
From Wells	141
Lucerne	189
Metal and Wooden Tappoons ..	175, 176
Nitrifying Organisms	140
Open Wells	147
Orchards and Vineyards	178
Pastures	189

	Page
Irrigation—	
Potatoes	187
Pumping Plant	143
Reservoirs	151
Return Waters	196
Rise of Ground-water	192
Rolling Lands	177
Root Crops	187
Screen Points for Wells	147
Sloping Land 165, 171,	180
Soil, Nature of	136
Sorghum 186,	232
Uniform Spread of Water	165
Water-box, with Trap	154
Well-making	149
When and How to Water	185
Wild Flooding	177
With Artesian Water, Results of	226
Land Drainage	243
Digging and Grading Trench	264
Directions for Laying out	248
Distance Apart and Depth of Pipe Drains	256
Ditching Tools	264
Farm Drainage	250
Hainault Forest Reclamation	246
How to Locate Drains	261
Importance of	265
In Great Britain	245
Kind and Size of Pipe	257
Natural and Artificial	253
Open Drains 249,	265
Pipe-drainage	255
Sub-soil Drainage	255
Surface Drainage	253
Surface Tension	252
Surveys and Grades	263
Table of Discharges	259
Table of Grades	259
Texture of Soils	251
Leaching Alkali Lands	214
Lucerne 189, 233,	241
Machinery, Artesian	91
Calyx Drill	96
Diamond Drill	95
Sub-Artesian	120
Magnesium Sulphate	208
Main Artesian Basin of Australia	8
Measures, Water, Table of	116
Mechanical Power from Bores	266
Meteorological Conditions of Australia	1
Methods of Irrigation in America	135
Monsoonal Rainfalls of Australia	1
Moree Artesian Irrigation Farm, Aeration of Bore water	238
Barley	229
Comparative Periodical Analyses of Water	242
Corn-Maize	231
Cotton	235
Day and Night Watering	238
Fruit Trees and Vegetables	231
Grasses	235
Lucerne	233
Mechanical Analyses of Soil	236
Oats	229
Results at	226
Sorghum	232
Wheat for Grain	229
Wheat for Hay	228
Mound or Mud Springs	20
Mulching Alkali Lands	214
Multiplication of Bores and Increase of Flow	76
New South Wales, Artesian Area of	12

Page

New South Wales—
Geology and Physiography of 12
Statistics of Boring 278
Night Irrigation 141, 238
Nitrifying Organisms ..140
Northern Territory ... 52
Ocean Outlet and Discharge 66
Oil-Engines 132
Orchards and Vineyards 178, 184
Pastures Irrigation ... 189
Pelton Wheel 270
Pera Artesian Irrigation Farm 239
Analyses of Water .. 242
Hay 241
Lucerne 241
Saltbush 240
Trees and Vines 241
Permanence of Artesian Supplies... 89
Petroleum in Bores .. 275
Porous Beds, Thickness of 29
Potato Irrigation 187
Potential Resources of Artesian Supply 77
Power Derivable from Artesian Bores 266
Preparing Land for Irrigation 161
Pressure of Bore Water 266
Prevention of Alkali .. 211
Of Water-logging .. 210
Pumping Plant 143
Queensland, Artesian Basin of 34
Blythesdale Braystone 26, 40
Boring, Statistics of 46
Early Artesian Bores 42
Geology and Physiography of 34
Historical Record of Bores 42
Irrigation, Statistics of 48

Page

Queensland—
Roma Bore, Outflow of Water and Gas at 274
Rainfall of Western Country 5
Remedies for Alkali .. 201
Reservoirs, Amount of Land that can be Irrigated from .. 141
Dimensions of and Evaporation ... 157
How to Build and Maintain 151
Results of Irrigation with Bore Water 226
Return Waters in Irrigation 196
Rise of Artesian Water 85
Rolling Downs Formation 25
Rolling Lands, Distributing Water on 177
Root Crops 187
Saltbush, American Experience 221
Atriplex Semibaccata 220
Cultivation of .. 215, 222
Fodder Value of 217
Pera Bore 240
Scraper 162
Screen Points for Wells in Sandy Strata 147
Shaping Land for Irrigation 161
Sloping Land for Irrigation 165, 171
Sodium Carbonate 207
Chloride 206
Sulphate 206
Soil, as to, in Irrigation 136
Black and Flood Loams 19
Containing Alkali .. 200
Sorghum 186, 232
South Australia, Geology and Physiography of 52

	Page
South Australia—	
Statistics of Boring	53
Spring Pole Boring Plant	121
Statistics of Boring, New South Wales	278
Queensland	46
South Australia	52
Western Australia	58
Sub-Artesian Water Supply	105
Divining Rod	120
Geology of Water-bearing Formation	110
Hints for Working the Plant	125
Locating Sites for Bores	119
Machinery	120
Means of Increasing Supply	111
Tunnelling for Water	114
Water Obtained from Below Hard Basalt	118
Sub-Irrigation	194
Sub-Soil, as to, in Irrigation	140
Tappoons, Metal and Wooden	175
Temperature of Artesian Water	69
Thickness of Porous Beds	31
Tunnelling for Water	114
Variation in Flow from Artesian Bores	83
Vegetable Growth, Eradication of Alkaline Salts by	204
Victoria, Geology and Physiography	50
Vineyard Irrigation	178, 184
Water, Amount Applied in Irrigation	135
Artesian, Increasing the Flow of	76
Carrying Alkali	201
Definition of Artesian	6
Other Sub-Surface Sources	116
Temperature of	69
Tunnelling for	114
Uniform Spread of	165
Water-bearing Rocks of Australia	8
Water-Box, How to Build	154
Watering Crops	163
Watersheds of Australia	4
Well-Making for Irrigation Purposes	149
Wells, Amount of Land that can be Irrigated from	141
Flowing and non-Flowing	7
Open	147
Western Australia, Geology and Physiography	54
Statistics of Boring	58
When and How to Water Crops	185
Wild Flooding	177
Windmill Pumping Power	128, 141
Wooden Flumes	159

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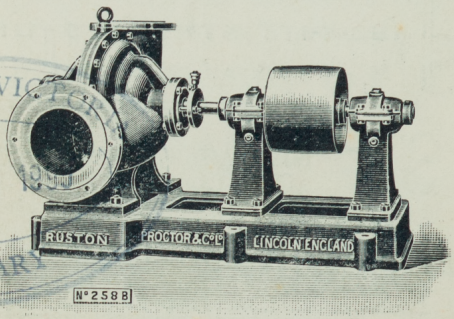

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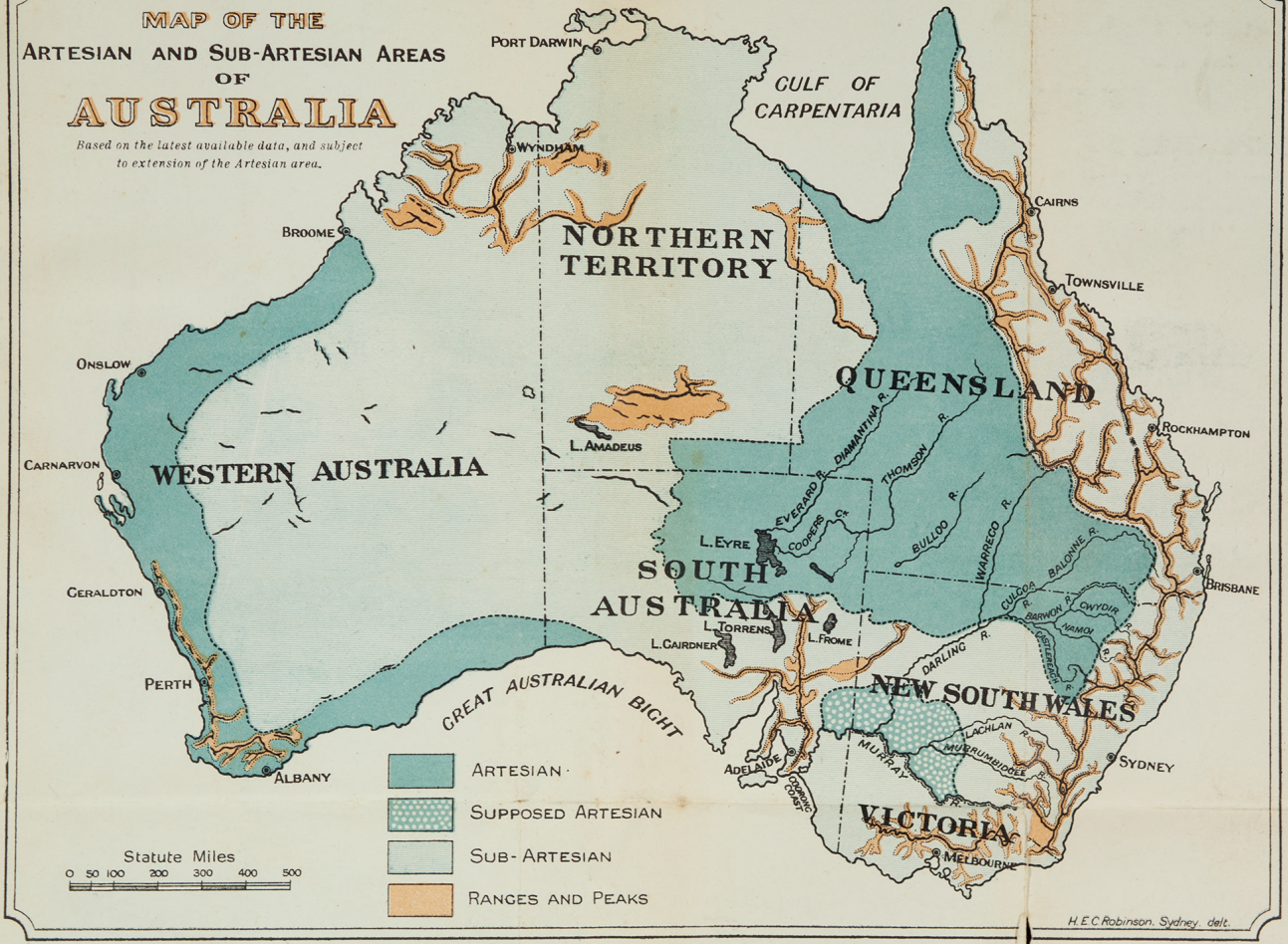

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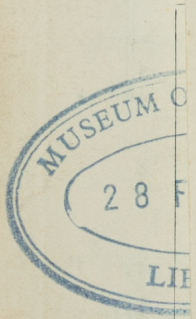

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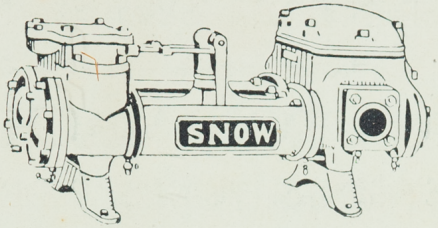

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